A Secondary BOOK of BIOLOGY

1. Common Core

MICHAEL GABB

A Secondary BOOK OF BIOLOGY

1. Common Core

BY M. H. GABB, B.SC.

Consultant: J. F. EGGLESTON, B.Sc., M.I.Biol.
Formerly Senior Science Master, Hinckley Grammar School

Macdonald Educational

Consultant's Foreword

In preparing this book we have been able to select from illustrations that have appeared in the magazine *Understanding Science*. These provide lucid, attractive visual communication which we think appropriate at this level. In addition there are many new illustrations. Where possible subjects are introduced by, or concluded by, practical and theoretical problem-solving material which provides opportunities for teachers to develop in their pupils an investigatory approach to the subject.

We have attempted to stimulate readers by the challenge of curiosity. Almost all the problem-solving material has been used with classes within the C.S.E. band of the ability spectrum, and their favourable reaction was the main criterion for its inclusion.

C.S.E. Biology is seen by the majority of the Regional Boards not merely as the acquisition of knowledge, but as an opportunity for the use of practical and cognative skills. The expectation is that assessment procedures which attempt to measure these abilities will have a beneficial 'backwash' effect; they will ensure that teachers whose concern is the development of these skills will be encouraged rather than inhibited by the way in which their product is measured.

One hopes that at least a start has been made on a generation of text books which incorporate this aim.

J. F. Eggleston.

This first volume is designed to cover the basic biology requirements of the various C.S.E. syllabuses. Supplementary volumes dealing with *optional* parts of the syllabus will follow, namely: 2. Genetics and Evolution, 3. Ecology and Applied Biology, 4. Bacteriology and Hygiene.

N.B. In all 'billiard ball' equations the atoms are coloured as follows: carbon-black, hydrogen-white, oxygen-red.

Acknowledgement

The editorial assistance of M. Chinery, B.A., and D. Larkin, B.Sc., is gratefully acknowledged. Miss Angela Ratcliffe was responsible for seeing the book through its various production stages. Most of the illustrations are by Mr. D. W. Ovenden, F.Z.S.

M.H.G.

Third impression 1970

Published by Macdonald & Co (Publishers) Ltd
49 Poland Street
London W.1

SBN 356 00013 3

Made and printed in Great Britain by Purnell and Sons, Ltd
Paulton (Somerset) and London

Contents

4. PLANT PHYSIOLOGY

1. Animal Classification

A

The Classification of Animals

In order to understand the importance of classification in Biology or in Chemistry, or Geology for that matter, it is useful to think about what happens when we classify, the way we think and what we do.

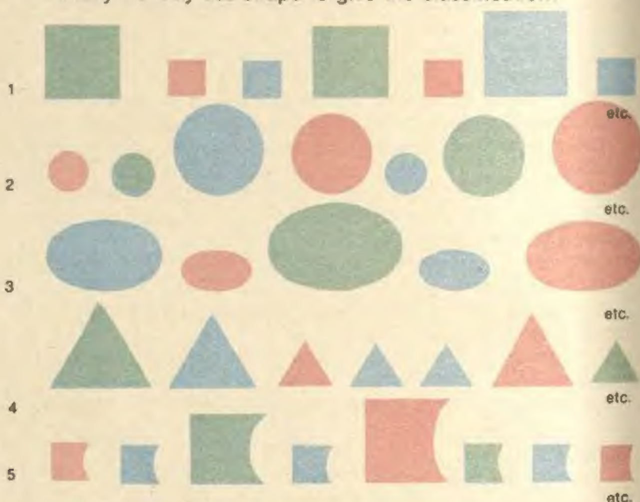
Study the diagrams and try to classify them into groups, in a way which you think gives a satisfactory classification.

It would be possible to use colour differences to give the following classification.

Alternatively, size could be used, but we would have to decide on the size limits for each class, e.g.

We could use the number of corners 0, 3 or 4 and classify the shapes in this way, but this would not distinguish between

Finally we may use shape to give the classification:



The problem is that of deciding which is the best way of classifying these objects.

Of the four methods described, colour and shape are the easiest to use, but is one of these better than the other?

We may argue that no matter what its colour, or its size, a rectangle is always identifiable as a rectangle. A 'red shape' would not mean very much nor would a red animal or a red plant. The first object of classifying is to be able to communicate, to pass on information about what you have seen. 'I have seen a rectangle' means more than 'I have seen a red shape'. The number of red shapes which exist is infinitely greater than the number of rectangles. If we describe VERY EXACTLY what we mean by a rectangle we cut down the number of images which comes into someone's mind when we use the word rectangle.

Thus classification by shape offers the best prospects for an efficient classification in this instance.

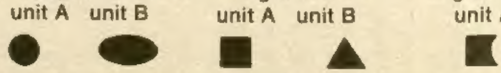
Main headings and sub-headings in classification

If we use this classification (by shape) we have five 'units' each with its own shape.

Now although each shape is different, some shapes are more similar than others. The ● shape and the ⬬ shapes resemble each other more than the other shapes. Again the ■ and the ▲ have only straight sides, the others do not. The ■ shape stands on its own.

We could group these units into 'bigger units'

big unit I		big unit II		big unit III
unit A	unit B	unit A	unit B	unit A



However, if you consider that having four sides, even if one

is curved, is more important than having straight sides, you may prefer a different classification.

The problem of names

a. Naming the units—in animal classification the following units are used.
   The smallest units are species, though they be subdivided into a smaller unit still, namely variety.
   A group of species makes up the larger unit, the genus.
   A group of genera makes up a class.
   A group of classes makes up a phylum.
   A group of phyla makes up a sub-kingdom.
b. International agreement has been reached on the names to be given to particular species and other units in particular cases and these are being revised as new facts are discovered.

Imagine the 'big units' above are genera, and the 'units' are species, and that you are the international committee naming the genera and species.

Call genus I Circulata (defined as having a circular or roughly circular shape).

Call genus II Rectangulata (defined as having a rectangular or roughly rectangular shape).

Call genus III Triangulata (defined as having a triangular shape).

Names must now be invented for each species; for example,

Genus I Circulata	Species a	py-r-squarus
	Species b	ovoidus
Genus II Rectangulata	Species a	fourectus
	Species b	bentendus
Genus III Triangulata	Species a	triangulatus

If (still imagining) a letter appeared in a learned scientific journal stating that a Rectangulata bentendus had been discovered at the North Pole, we would know exactly what had been discovered, so would everyone else who was interested no matter what part of the world they came from.

'Lumpers' and 'splitters'

The people involved in classification have different methods of approach to their subject. Some look for the similarities between living things; others look for differences. There is a tendency for the first group to lump small units together to make big units and for the latter group to split small units into still smaller units. It is quite wrong to regard the present classification as fixed, or even correct in every detail. Consider what would happen if the genus Triangulata was given a detailed examination by a 'splitter' and he found that triangles of two distinctly different types could be recognised, acute and obtuse, and He would scrap the species Triangulata triangulatus and invent two other species perhaps, Triangulata acuta and T. obtusata.

Inventing 'keys' for identification

Once a classification has been invented, it is possible to produce a 'key' by which a particular species can be identified. To illustrate the way keys are devised and used we can take our classification of shapes and produce a key for the identification of any one of the five shapes.

With the unknown species (shape) in front of you simply read each description and by following the numbers proceed to the next appropriate line.

	shape outlined by a single unbroken line	2
	shape outlined by two or more lines	3
2.	an exactly circular shape	Circulata py-r-squarus
	an oval shape	C. ovoidus
3.	a four-sided figure	4
	a three-sided figure	Triangulata triangulatus
4.	four straight sides	Rectangulata fourectus
	three straight sides and a fourth side markedly bent	R. bentendus

Thus if you have a shape in front of you, working through the key would be:

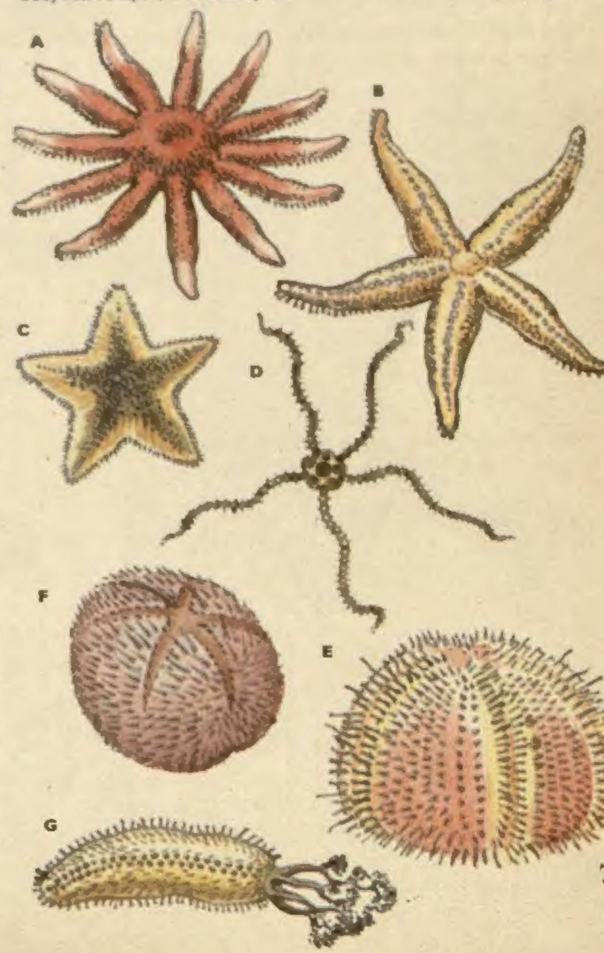
	shape outlined by two or more lines	3
3.	four-sided figure	4
4.	three sides and a fourth side markedly bent	R. bentendus

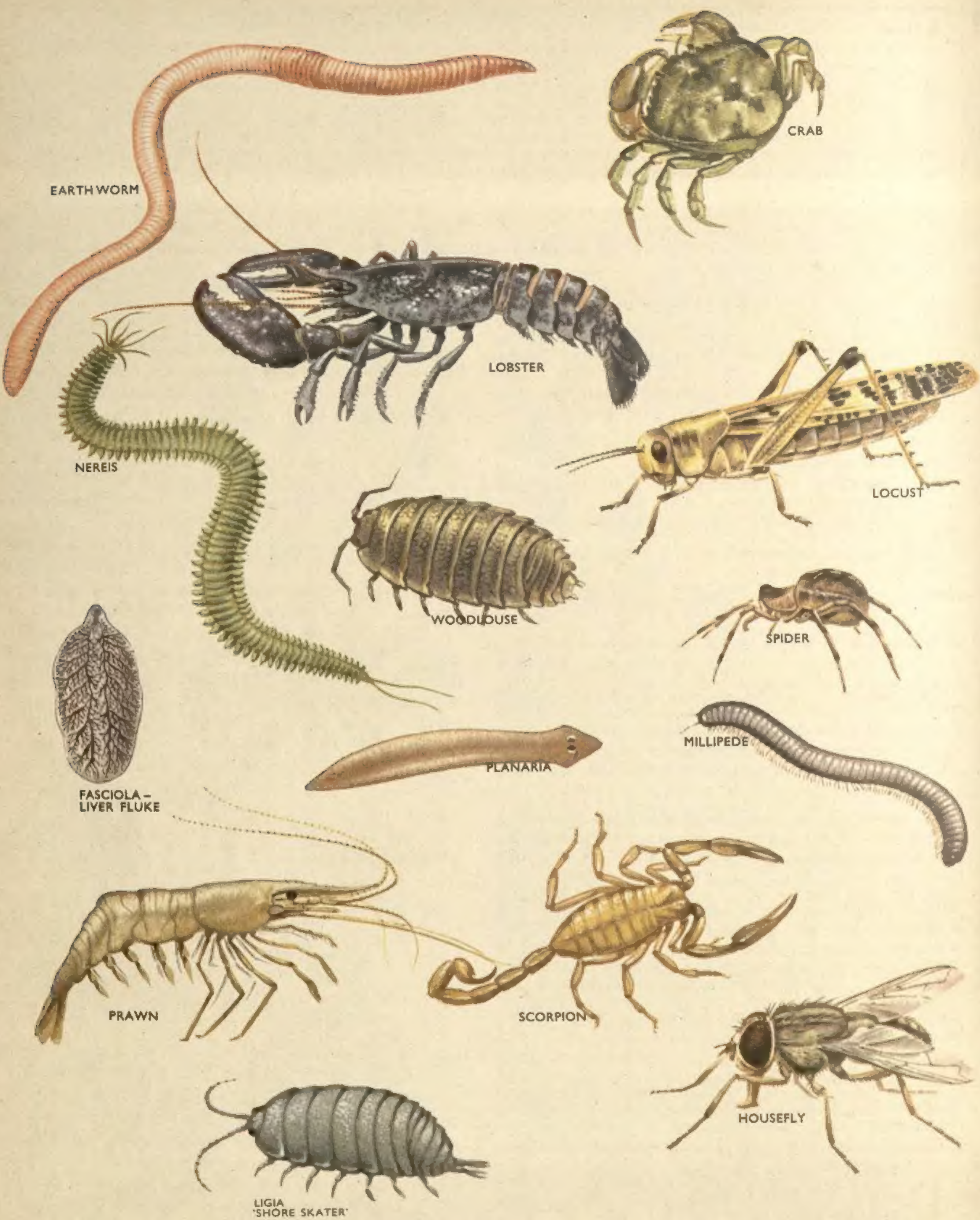
A Problem

Study the illustrations and work through the key, naming A-G. This key is of use only for identifying the seven examples given, it is not intended to be a general key for identifying echinoderms.

Are all the animals shown echinoderms? Most echinoderms are radially symmetrical (i.e. limbs and other organs are arranged around a central point) though in some sea urchins (heart urchins) and sea cucumbers the shape and arrangement of organs are not the same along all the radii. Echinoderms have rows of tube feet along the radii.

	Animal star-shaped	2
	not star-shaped	5
2.	Arms not divided from body (disc)	3
	Arms clearly divided from disc	Ophiothrix fragilis
3.	Five arms	4
	More than five arms	Solaster papposus
4.	Arm length much more than half radius of starfish	Asterias rubens
	Arm length about half radius of starfish	Asterina gibbosa
5.	Spherical or heart-shaped and covered in spines	6
	Gherkin-shaped without spines	Cucumaria normani
6.	Body spherical, with long spines	Echinus esculentus
	Body heart-shaped, with weak spines	Spatangus purpureus




CRAB
EARTHWORM
LOBSTER
LOCUST
NEREIS
WOODLOUSE
SPIDER
MILLIPEDE
PLANARIA
FASCIOLA –
LIVER FLUKE
PRAWN
SCORPION
HOUSEFLY
LIGIA
'SHORE SKATER'

Problem

(a) Sort these animals into groups. Write down lists of their names. In each list place the animals that are similar. How are you going to decide which animals are in the same group?
(b) Make a list of the parts common to all members of the same list.
(c) Invent a name for each list.
(d) How could you name a particular type of animal in each list?
(e) Why are some types of animals more similar than others?
(f) If you classified the members of your class what kind of difficulties would prevent you making a good classification?
(g) If you found two boys or two girls almost exactly alike what would you assume? How does this help you to answer (e) above?
(h) Invent a key for identification.

In any small area you will find many different kinds of animals. In your garden, for example, you may come across earthworms, slugs, snails, centipedes, millipedes, beetles, earwigs, woodlice, spiders, mice and lizards. There are very obvious real differences between these creatures, differences that provide the basic division of the animal kingdom into different kinds of species.

Over a million species of animals are known at present and many more are discovered each year. Anyone who studies animals must be able to refer to any one animal by its individual name. Each animal is in fact given two names; its specific name or *species* and its generic name or *genus* (a genus is a group of closely related species; a species is a group of animals or plants that breed among themselves but normally not with other related groups). The specific name of the domestic horse, for example, is *caballus*. Its generic name is *Equus*. Its full name is *Equus caballus*, with the generic name first and the specific name second. The African wild ass—and the zebras—are also included in this, the genus *Equus*, but they are different species. The former is called *Equus asinus*, and one species of zebra is called *Equus zebra*. These names apply in all countries. Common names could not be used in this way, for they vary so much from one place to another. The same common name may apply to two quite different animals. The robin in America, for example, is not the same as the European robin.

A system of classification is more than a division of the animal kingdom into genera and species; these are merely the finest divisions. The animal kingdom is in fact divided into about twenty major groups called *phyla* (singular phylum). Each phylum contains animals with certain basic similarities. Within each phylum some animals are more alike than others and these are separated into *classes*. Classes may be subdivided into *sub-classes*; these into *orders*, orders into *suborders*, suborders into *families*, families into *genera* and genera into *species*.

The members of a large division, therefore, have fewer characters in common than those in a subdivision. For example, Mammals and Bony Fishes are vertebrates, that is they have a backbone and a hollow, dorsal nervous system, part of which forms a brain that is protected by a braincase. However, Mammals have hair, suckle their young, have limbs and are warm-blooded. Fishes lack hair and have a scale-covered body; they have fins and not limbs, the young generally hatch from eggs which are laid, and they are cold-blooded. Both are placed in separate sub-groups of the Vertebrata.

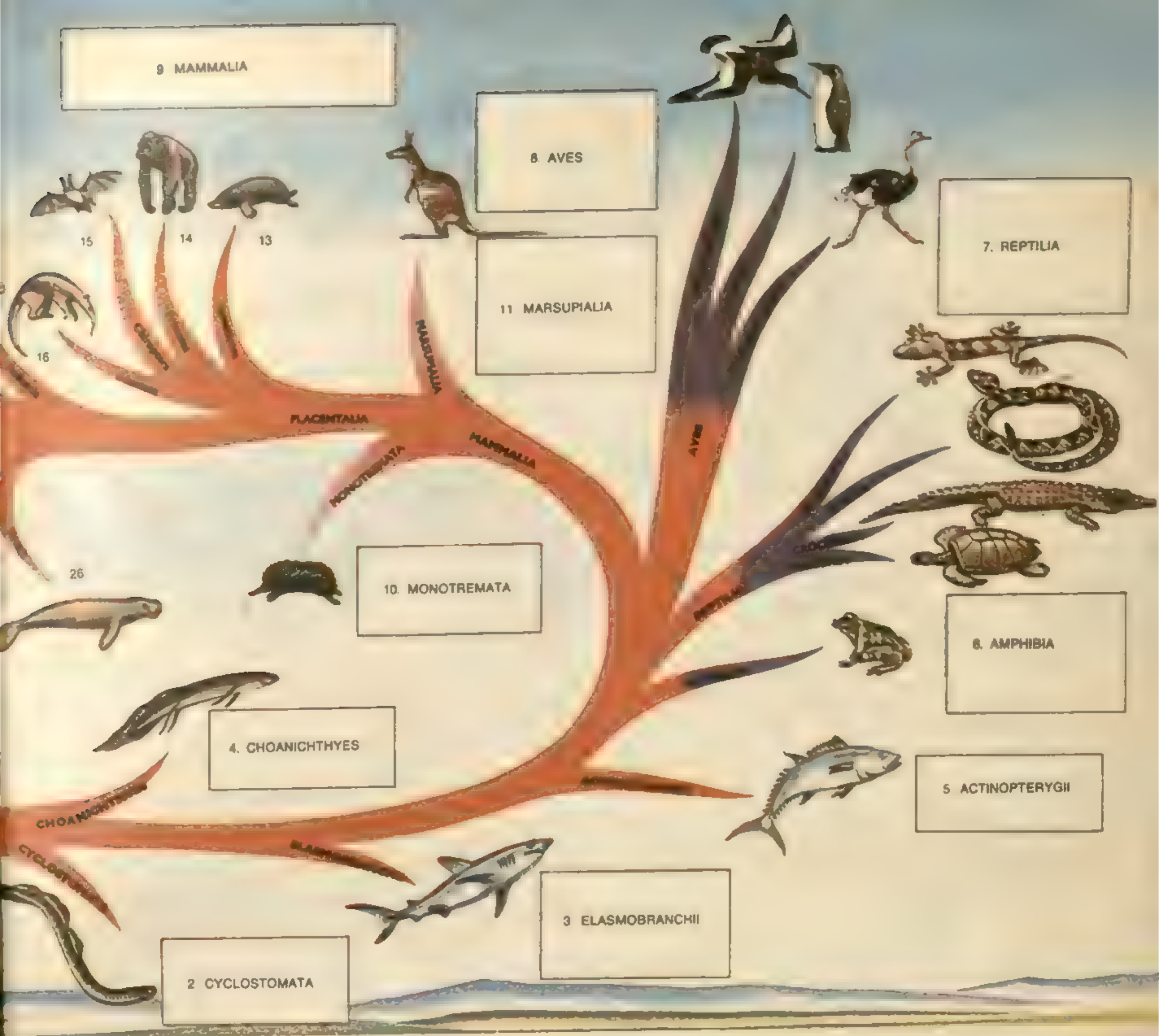
If we classify man, starting with his mammal grouping (Class: Mammalia) we can see how his genus and species rankings are arrived at. He is a placental mammal (sub-class: Placentalia) which is based on a number of characters. He belongs to the order Primates along with the tarsiers, lemurs, apes and monkeys—all animals with binocular vision, similar skeletons, etc. Only the apes and monkeys are included with man in the sub-order Anthropoidea and only fossil man is in the same family, Hominidae. His genus *Homo* is the same for Neanderthal man, but the latter's species is *neanderthalensis*, while man's is *sapiens*.

Man's classification as described here may be summarised as:

Class:	Mammalia
Subclass:	Placentalia
Order:	Primates
Suborder:	Anthropoidea
Family:	Hominidae
Genus:	Homo
Species:	sapiens

Man is a backboned animal (i.e. vertebrate) which places him in the sub-phylum Vertebrata. Below this, his phylum ranking is the Chordata (all animals that at some stage in their life possess gill slits and an elastic supporting rod or notochord and always have a hollow dorsal nervous system, i.e. one in the back). Vertebrata and Chordata would be placed above class Mammalia in a fuller classification.

1. *Protochordata*—chordates that have no true brain and no braincase or backbone. They lack a heart and the type of kidney typical of vertebrates. Examples are the sea squirts, lancelets and acorn worms.
2. *Cyclostomata*—vertebrate chordates with an endoskeleton of cartilage. They have no jaws and lack scales and bones. The lampreys, hagfishes and slime hags are examples
3. *Elasmobranchii*—fishes with well-developed jaws. They have an endoskeleton made of cartilage; bone is entirely lacking. The skin is covered with horny, teeth-like scales. Only the king herring has its gill slits covered by an operculum.
4. *Choanichthyes*—fishes with internal nostrils. Their paired fins have fleshy lobes. The coelacanth and lung-fishes are examples.
5. *Actinopterygii*—ray-finned fishes with well-developed jaws. They have an endoskeleton made almost entirely of bone.
6. *Amphibia*—cold-blooded vertebrate animals that usually need to return to water to breed and, except in some limbless forms, lack scales. They usually have lungs and a moist skin through which they can breathe. Examples are frogs, toads, newts and salamanders.
7. *Reptilia*—cold-blooded vertebrates fitted for life on land. The skin is dry and covered in scales. They have lungs and show an advance on amphibians in laying shelled eggs which hatch on land. Examples are the crocodiles, snakes, turtles and lizards.
8. *Aves*—warm-blooded vertebrates that have feathers. Like reptiles they lay shelled eggs. Another reptilian characteristic is the presence of scales on the legs and feet. The fore-limbs are modified as wings.
9. *Mammalia*—warm-blooded vertebrates that have hair. The young are nourished with milk which is provided by milk or mammary glands and, except in the monotremes which lay eggs, the young are born alive.
10. *Monotremata*—the egg-laying mammals. Examples are the platypus and spiny ant-eater. Neither animal has teeth.
11. *Marsupialia*—the pouched mammals. Forms which bear their young alive, but in a small, relatively unformed state. The female has a pouch on the lower part of the abdomen in which the young are carried and suckled until they are able to fend for themselves. Examples are the kangaroos, wallabies, koala and opossums.



12. *Placentalia*—mammals in which the young during their early development are connected to the mother by a 'plate' of tissue, the placenta. This passes on food, oxygen and chemicals to the embryo. The young are born at a more advanced stage than in other mammals. They feed on milk from the mother for some time after birth. Placentals have no pouch. Examples are the rodents, cats, dogs, horses, sheep, monkeys, apes and Man.
13. *Insectivora*—primitive insect-eating placentals.
14. *Primates*—mostly tree-dwelling placentals; big toe and thumb often well developed and can be moved to other digits in order to grasp objects.
15. *Chiroptera*—the only mammals capable of flapping flight. The wing is a membrane supported by the elongated fingers and stretched between each arm and leg.
16. *Edentata*—placental mammals that have teeth very reduced or absent.
17. *Rodentia*—placental mammals with one pair of gnawing teeth in each jaw.
18. *Lagomorpha*—placental mammals with two pairs of gnawing teeth in the upper jaw and one pair in the lower jaw.
19. *Cetacea*—placental mammals that spend all their life in water. They have paddle-like forelimbs and no hindlimbs.
20. *Carnivora*—mostly flesh-eating placentals.
21. *Artiodactyla*—even-toed ungulates or hoofed mammals.
22. *Perissodactyla*—odd-toed ungulates.
23. *Tubulidentata*—placental mammals with peg-like teeth. The aardvark is the only living example
24. *Proboscidea*—placentals with a trunk, long incisors forming tusks and immense grinding molars.
25. *Hyracoidea*—'rabbit-like' placentals with hoof-like nails or claws, one pair of continually growing incisors in the upper jaw and two pairs in the lower jaw.
26. *Sirenia*—plant-eating placentals highly adapted for life in water. The hindlimbs are not visible externally; fore-limbs paddle-like.

The Major Animal Groups or Phyla

PROTOZOA
Minute, single-celled animals. The majority live in the sea and fresh water, though some live in damp soil and others live inside larger animals. Many have short hairs (cilia) or long hairs (flagella) which beat to move the animal from place to place or draw a water current containing food and oxygen towards them. Some are naked masses of living jelly (protoplasm), while others have elaborately patterned shells of chalk or silica.

PORIFERA
(Sponges) Many-celled animals that live in water attached to the bottom. Some live singly, others are joined together to form colonies. The body surrounds a single cavity which is lined by special collared cells, each of which possesses a long hair or flagellum. The body wall has numerous pores in it through which water passes in, and one or more large openings through which it leaves. Often the body wall contains a skeleton made up of branched sandy or chalky structures called spicules.

COELENTERATA
(Hydroids, corals, sea anemones, etc.) Many-celled animals with a body wall made up of two layers of cells between which is a jelly-like middle layer. The body wall surrounds a hollow cavity, the enteron, which has a single opening, the mouth, in through which food is taken and out through which waste is ejected. The nervous system is a network of cells or at the most a simple nerve ring. Coelenterates reproduce by means of larvae, but budding is also a common method of reproduction. Some live singly but others are joined together to form colonies.

PLATYHELMINTHES
(Flatworms) These many-celled animals have a body made up of three layers. The gut (if present) has only one opening, the mouth. They lack a blood system but show the beginnings of a central nervous system, for, besides a nerve net similar to that of coelenterates, they have a small mass of nerve tissue at the head end from which thick strands pass backwards. The organs of excretion are called flame cells.

NEMATODA
Commonly called roundworms, these are long cylindrical worms with an unsegmented body which is pointed at both ends. Many forms are parasitic but some occur free in the soil. They inhabit most situations, fresh and salt water, the soil, and plants and animals, causing much damage to crops and farm animals.

The body wall is almost transparent. The sexes are separate. The nervous system is not well developed and consists of a ring around the oesophagus with fine branches.

ANNELIDA
(Ringed or segmented worms) The body is made up of a number of segments and is three-layered. The body wall is muscular and contains an outer circular layer of muscle fibres and an inner longitudinal layer of muscle fibres. Between the body wall and the gut there is usually a well-developed cavity or coelom. The nervous system consists of two swollen masses of nerve cells (ganglia) in the head connected underneath the gut with a pair of nerve strands (cords) which run the length of the animal and are swollen to form a pair of ganglia in each segment. The excretory organs, of which there are usually a pair to each segment, are called nephridia (singular: nephridium).

BRACHIOPODA
(Lamp shells) Unsegmented animals with a body cavity and a two-halved shell. Food is carried to the mouth in a current of water produced by the short hairs (cilia) on a spiral organ which consists of two spiral arms joined together just above the mouth.

POLYZOA
(Moss animals) Animals whose bodies are unsegmented and have a body cavity or coelom, a ring of tentacles around the mouth, and a 'U'-shaped gut. The nervous system consists of a ganglion near the mouth from which nerves pass to various parts of the body. There is no blood system. They nearly always live in colonies, on seaweeds, rocks and on other suitable structures.

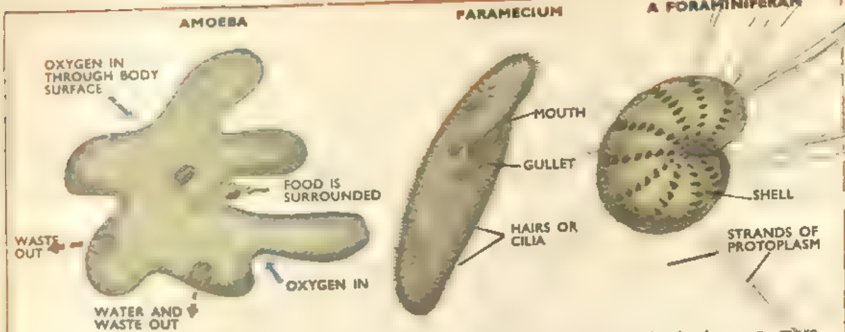
MOLLUSCA
(Snails, slugs, bivalves, octopuses, etc.) Animals with soft unsegmented bodies containing a coelom and usually having a shell of lime salts secreted by the mantle, a soft skin covering the gut and associated organs. The shell may be external (bivalves) or internal (e.g. slugs and octopuses). They have a definite head, a muscular foot on the lower side, and usually breathe by means of gills. A part, or parts, of the mantle encloses a cavity into which the anus and kidney empty. Nervous system consists of a ring (this may contain ganglia) round the oesophagus with strands to ganglia in other parts of the body.

ARTHROPODA
(Insects, spiders, crabs, centipedes, etc.) Segmented animals with jointed limbs, a strong jointed outer or exoskeleton, a nervous system on the same plan as the Annelida (i.e. head ganglia connected to a double nerve cord underneath the gut. The cord is swollen as a pair of ganglia in each segment). Some or all of the segments bear a pair of jointed limbs, at least one pair of which form jaws.

ECHINODERMATA
(Sea urchins, starfishes, etc.) Spiny-skinned animals that are radially symmetrical (that is, their body organs are arranged around a central point or plane). They have a basic five-rayed plan and a skeleton made up of chalky plates in the body wall. The body cavity is divided up into a series of compartments each of which performs a separate function. Along the five 'rays' are rows of hollow tube feet which project through the body wall. These are used in locomotion and sometimes in feeding.

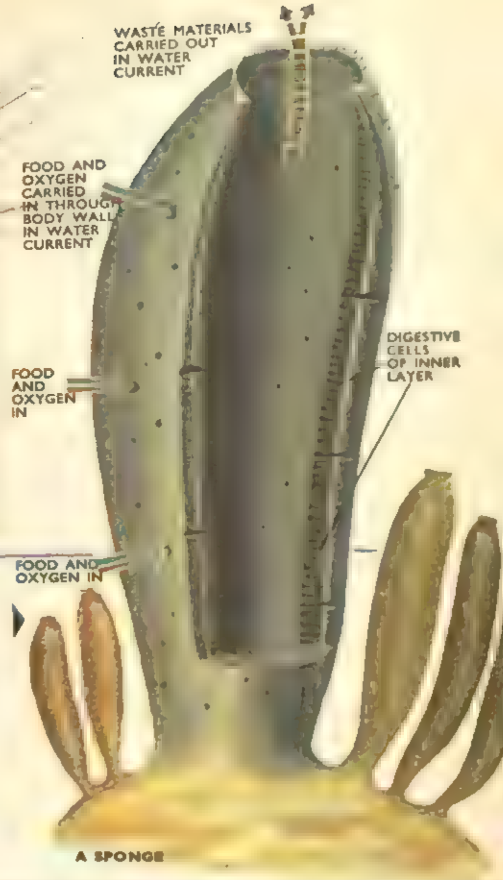
CHORDATA
(Sea squirts, lampreys, fishes, frogs, reptiles, birds, mammals, etc.) Animals which at some stage in their life have gill slits and a supporting rod of elastic material (the notochord) and always have a hollow dorsal nerve cord (i.e. one which runs through the back). In frogs, reptiles, birds and mammals, the notochord is replaced by the backbone which takes over the role of support. Frogs only have gills as tadpoles. In reptiles, birds and mammals gill slits show at an early stage of development but later disappear.

The Structure of Animals



Some animals are single-celled All the processes that are fundamental to life, such as feeding and breathing, are coped with by the one cell

Many single-celled animals have a more complicated structure than *Amoeba*. Some have a mouth and a gullet, whip-like hairs which they beat in order to move about, and others have elaborate skeletons made of chalky or sandy materials

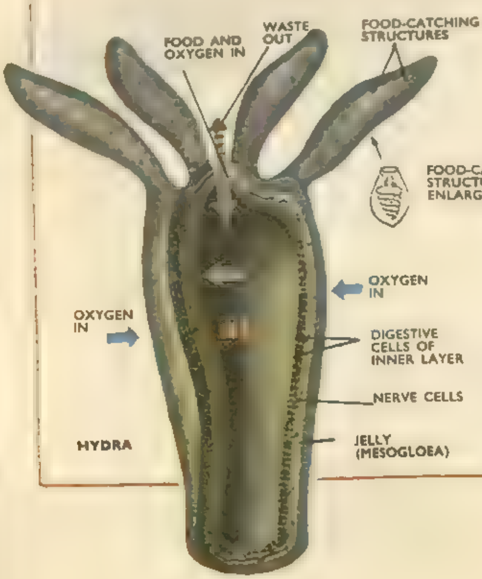


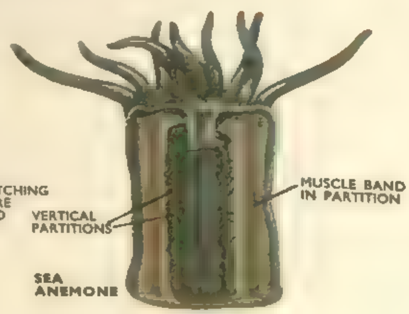
Sponges are simple many-celled animals. They are made up of a loose collection of cells. The body's functions are carried out by individual cells in a relatively uncoordinated way There is no mouth or gut and no organ systems. The majority are branching and plant-like and the walls are perforated by many small openings Water enters through some of these and leaves through others. The cells that create the water current take in food particles and digest them.

Most sponges have a skeleton made up of needle-like *spicules*, or horny fibres or both. A few occur singly but most are colonial.

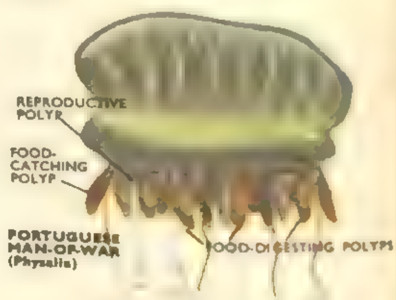
Coelenterates (e g jellyfish, hydroids) are many-celled animals whose body wall is two-layered (with an intervening layer of jelly) and surrounds a hollow cavity into which the mouth opens. There is a simple nervous system giving a certain degree of co-ordination between different parts Some of the cells of the inner layer are specialised for digesting food materials In the outer layer there are specialised food-catching structures (nematocysts)

Some live as single individuals (e g sea anemones), while others (e g most corals) are colonial

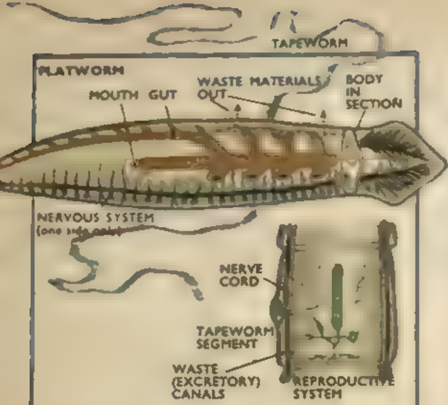




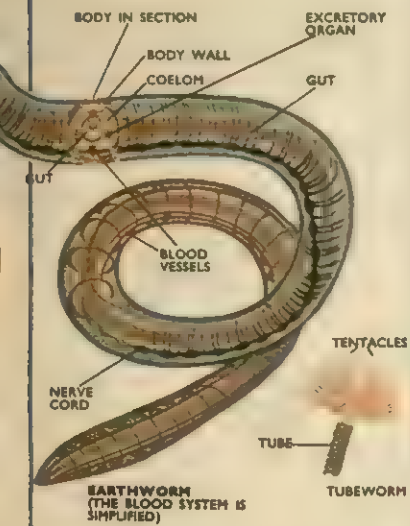
Many coelenterates have a more complicated structure than that of *Hydra*. Sea anemones, for example, have the body cavity divided up by vertical partitions. Special bands of muscle enable them to contract rapidly.



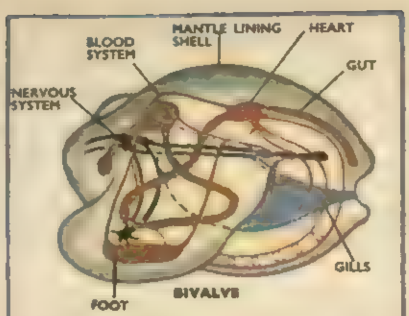
In many colonial coelenterates certain of the individuals (polyps) serve different functions Some catch food and pass it to another to be digested while others are reproductive

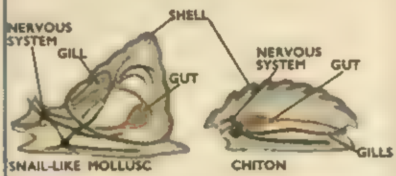


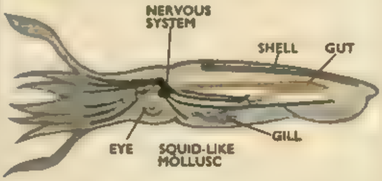
Animals such as flatworms have a three-layered body wall but it is solid tissue—there is no body cavity or coelom as in earthworms, for example. But flatworms have elaborate organ systems compared with coelenterates though the gut is still a hollow tube with only one opening to the outside. Parasitic forms like tapeworms absorb food from their surroundings—they have no gut.



Earthworms and other annelids have a three-layered body wall but between it and the gut there is a cavity or coelom which contains the 'kidneys' and reproductive organs. The gut runs the entire length of the body and has a mouth at the front and a rear opening, the anus. The body is divided into segments which are separated from each other by a partition. Most of the segments are identical in structure. The blood system is well developed and the double nerve-cord runs the length of the worm below the gut. There are pairs of nerve swellings (ganglia) on the cord in each segment. Worms such as the earthworm have no hard skeleton but others build themselves protective tubes. Many such worms have elaborate fans of tentacles with which to catch food.

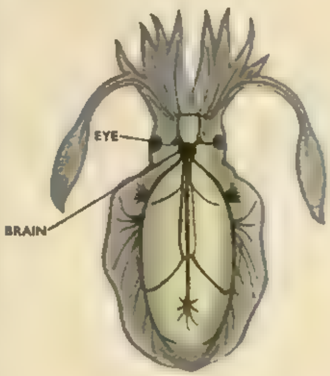




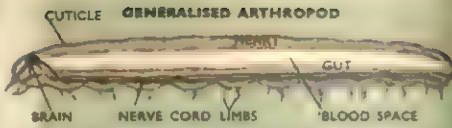


Molluscs (e.g. snails) have a soft unsegmented body with a three-layered wall. The body cavity is small. They usually have a shell of lime salts which may be external (as in snails, clams, etc.) or internal as in slugs, cuttlefish, etc. It may be 'one-piece' (e.g. snails) or in two pieces (e.g. clams). The lower side of the body forms a muscular foot used for moving about and they usually breathe by means of gills. These are also used by bivalves to collect minute particles of food

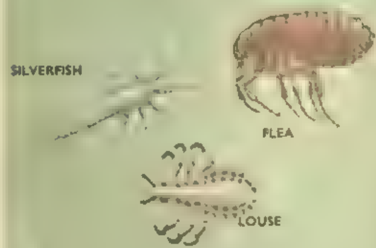
CUTTLEFISH



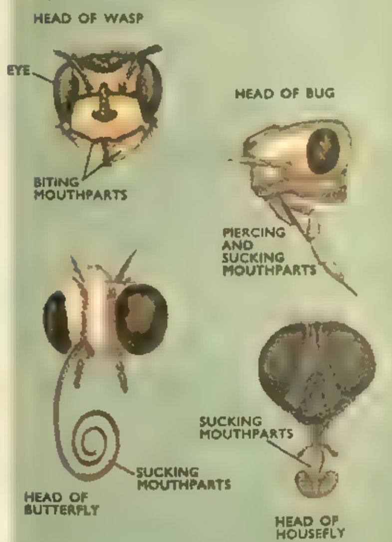
Squids, octopuses and the like are more active than other molluscs. They have large eyes and a well-developed nervous system.



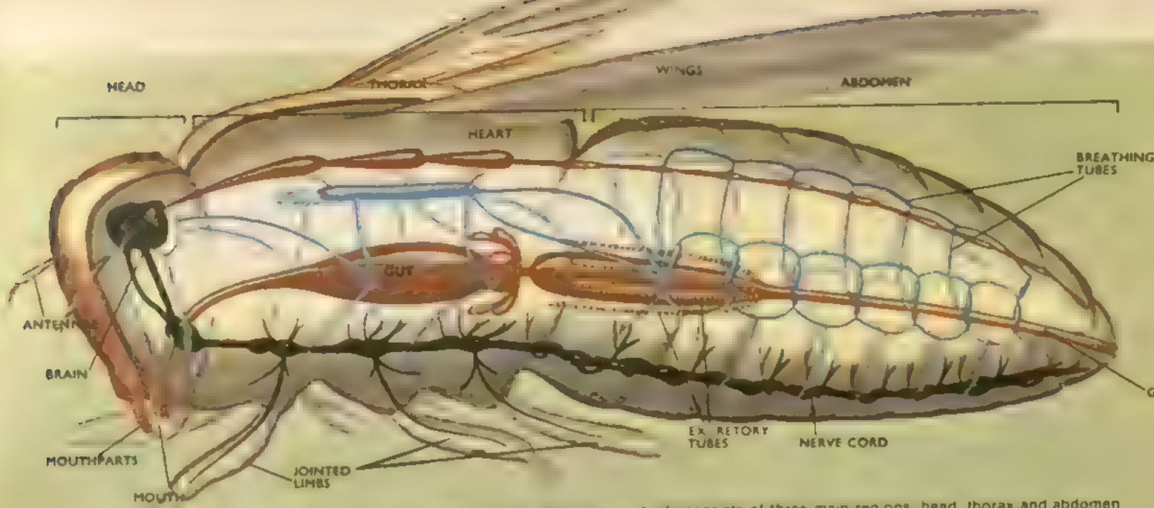
Many invertebrates (arthropods) have a hard outer skeleton (exo-skeleton) which is jointed and made of horny protein and chitin, which may be impregnated with lime salts (as in crabs, for example). The nervous system consists of a brain (head ganglia) and a double nerve cord beneath the gut. The body is segmented and many of the segments bear paired limbs. The body cavity is reduced in the adult but there is a large blood space in which the blood is circulated



Some insects are wingless. Of these, fleas and lice, for example, are specially adapted as parasites



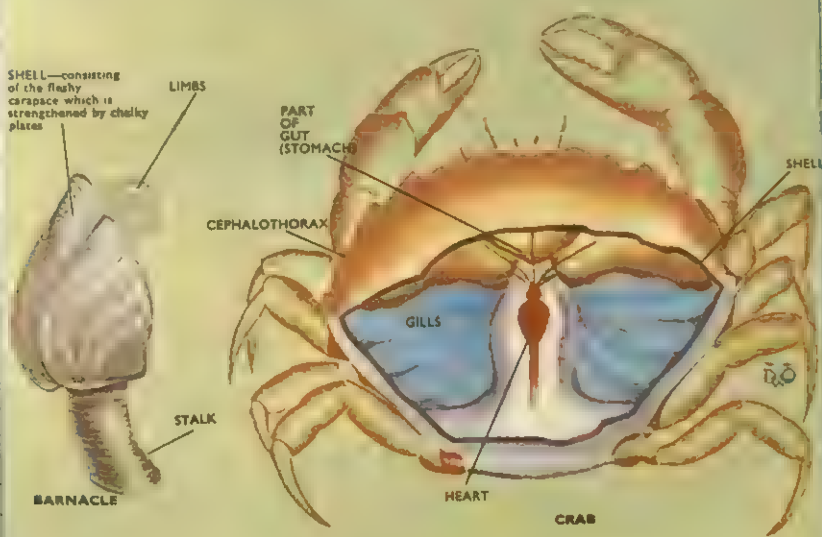
There is great variation in the mouthparts. Wasps have biting mouthparts, many bugs have them adapted for piercing plants and animals and sucking the juices. Butterflies have long tubular mouthparts for feeding at flowers. The housefly has a large pad through which it sucks up liquid food.



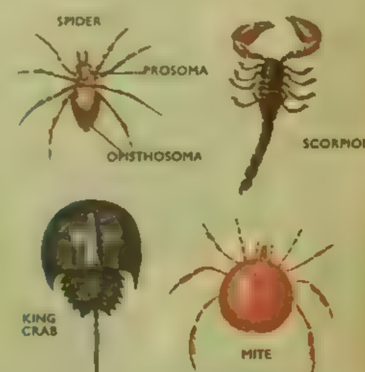
A GENERALISED INSECT

Insects are arthropods whose body consists of three main regions head thorax and abdomen The thorax usually bears wings and three pairs of walking legs The head bears a single pair of feelers (antennae) and jointed mouthparts used in food collection and in some forms for defence They have a special system of breathing tubes or tracheae

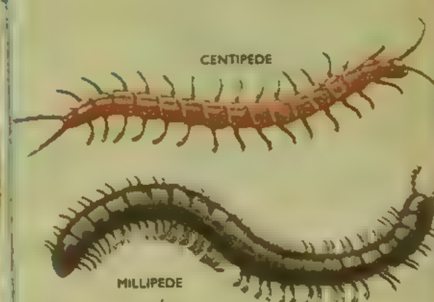
Many arthropods (crustaceans such as crabs and lobsters) have a hard crusty covering – the skeleton is impregnated with lime salts which often forms a breastplate or carapace Crabs lobsters, prawns and shrimps have the segments of the thorax fused with the head and carapace, forming the cephalothorax. Most crustaceans live in water and breathe by means of gills.



Barnacles are crustaceans that live fixed to the sea bottom or to marine piles and the like – the carapace surrounds the trunk.



Arachnids (spiders, scorpions, mites, ticks and king crabs) are arthropods in which the body is divided into two regions a front prosoma and a rear opisthosoma The latter may be divided into two Adult spiders mites and scorpions have four pairs of walking legs.

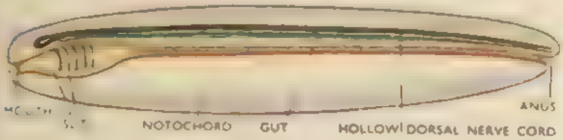


Myriapods (centipedes and millipedes) have many similar leg-bearing segments and a tracheal system. The head is a well-defined region. Centipedes have one pair of legs per segment, and millipedes two pairs per segment.

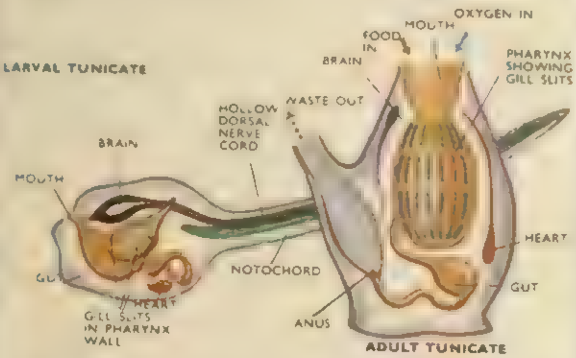
Chordates

ANIMALS in the group that includes the sea squirts, acorn worms, lancelets, hagfishes and lampreys, fishes, amphibians, reptiles, birds and mammals are called *chordates* (the group name is *Chordata*). At some stage in their life chordates have *gill slits*, a supporting rod of elastic material, the *notochord*, and a *hollow dorsal nerve cord*.

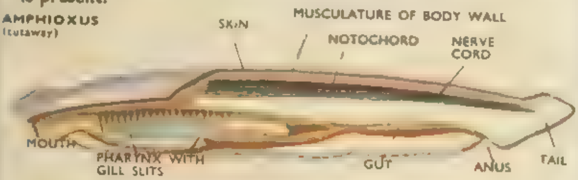
THE FEATURES OF A TYPICAL CHORDATE



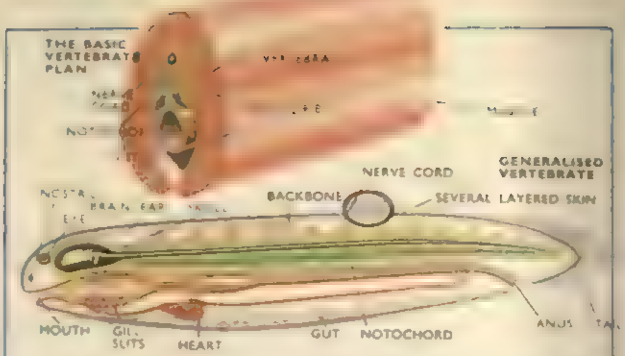
The larva of a tunicate (sea squirt) shows clearly the basic chordate features, far better than the adult does. It has a hollow dorsal nervous system, the tail is supported by a notochord, and though the gut is not well developed (the larva does not feed) it usually has a pair of gill slits.



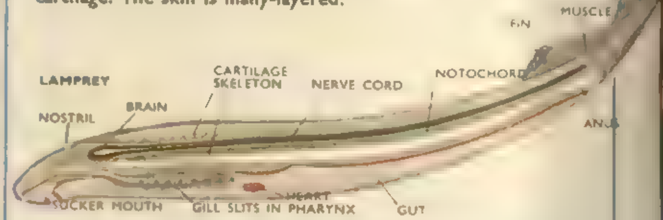
The adult tunicate has no notochord, and the central nervous system is a solid nerve mass or ganglion, but the pharynx has gill slits whose cilia beat to draw a water current carrying food and oxygen. There is no coelom but a body cavity of another kind is present.



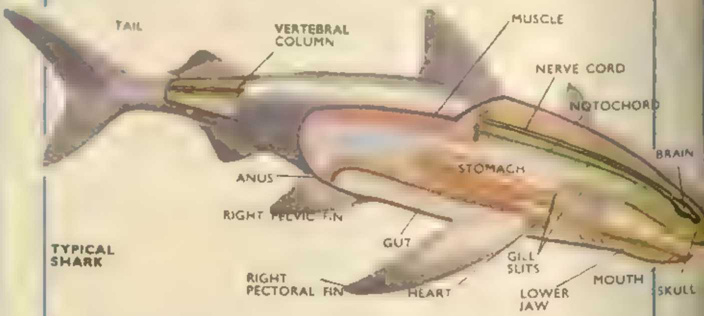
The lancelet (*Amphioxus*) displays the features of a typical chordate. The body is fish-shaped and flattened from side to side. The muscles consist of a series of blocks the fibres of which work to bend the body from side to side. The gut is a long tube with a mouth and anus and the wall of the pharynx is perforated by gill slits; the gills are ciliated. The cilia beat to draw a water current containing food into the pharynx. There is a coelom (body cavity) around the gut. The notochord is an elastic rod (the length of the body) beneath the hollow dorsal nerve cord. It stops the body from shortening when it bends during movement. The skin consists of only one layer.



All other chordates have a skull (*cranium*) and a backbone (*vertebral column*), though the latter is not always well developed—they are called *vertebrates*. The front end of the nervous system is enlarged to form a brain. Associated with this are the special sense organs—the eyes, nose and ears. The pharynx is small compared with that of the invertebrate chordates and the gills are used in respiration and *not* for food-collecting. The vertebrate blood system has a heart with at least three chambers (*Amphioxus* has no heart) and there is an internal skeleton of bone and/or cartilage. The skin is many-layered.

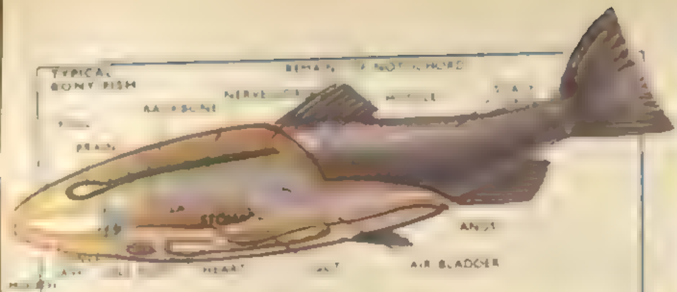


The simplest vertebrates (lampreys, hagfishes, etc.) have no jaws. The mouth is surrounded by a large, round sucker. The tail has a fin which extends forwards halfway along the back and the muscle blocks are W-shaped. The skeleton is made up of the notochord and cartilage.



The sharks, rays and skates (cartilaginous fishes) have an internal skeleton of cartilage—bone is entirely absent. They are the simplest of the living vertebrates with jaws. The 'skull' is better developed than in the jawless vertebrates. In all except the king herrings the gill slits are visible and not covered by a gill flap or operculum as in bony fishes. The gills are respiratory. The skin is covered with horny teeth-like scales and on the jaws these are modified to form teeth. The dorsal lobe of the tail is larger than the ventral lobe. Besides the dorsal fins (typically two in number) there are two pairs of paired fins. Each paired fin has a supporting structure at the base—*pectoral* (shoulder) girdle and *pelvic* (hip) girdle. The notochord is reduced and largely replaced by vertebrae—short ribs are present in the front region. Movement is produced mainly by the serial contraction of the fibres of successive muscle blocks—arranged essentially as in simpler chordates. The gut is more elaborate and divided into more obvious regions.

Skates and rays are cartilage fishes in which the body has become flattened dorsoventrally (i.e. from above and below).

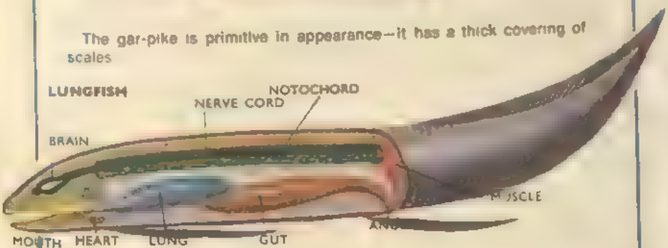


Most fishes have an internal skeleton mainly composed of bone. The bony fishes include the teleosts, lung-fishes, and several surviving primitive forms such as the bichir, gar-pike and the sturgeons (in the latter bone is very much reduced and the skeleton is almost wholly made of cartilage). In shape the typical teleost (e.g. salmon) is more streamlined than the cartilage fishes, being more flattened from side to side. The tail is usually symmetrical. The paired fins are small and have supporting rays. The scales are thin and flat, not tooth-like as in sharks. The mouth is larger and the lower jaw more mobile than that of sharks. The gills are covered by a flap, the operculum, and the skull has a complicated structure. The jaws are made up of several bones. The vertebral column is better developed than in sharks and bears more prominent ribs. Thin protective pads (the remains of the notochord) occur between each vertebra. A feature not found in sharks is the air bladder – an air-filled sac used as a floating device. The brain is better developed than in sharks.

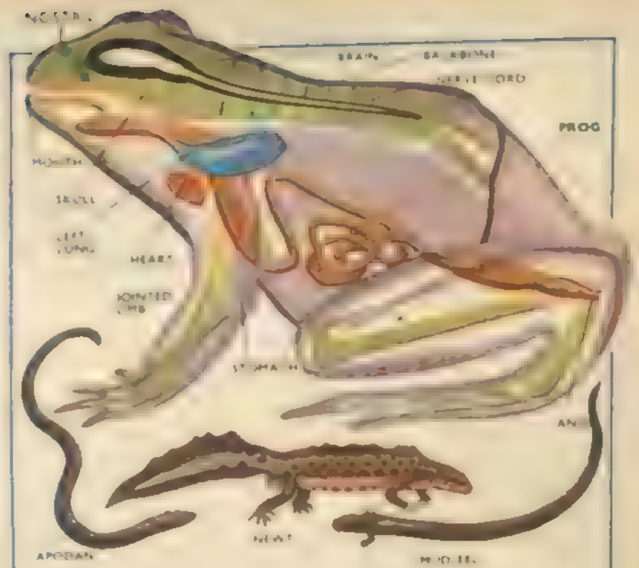
There is a considerable range of size and form in teleosts – the varying position of the paired fins is of use in classification.

The bichir, *Polypterus*, is a bony fish whose body is covered with thick over-lapping and diamond-shaped (rhomboid) scales. There are many more bones in the skull than in teleosts. The air sacs (lungs) are paired like those of four-limbed animals (e.g. mammals).

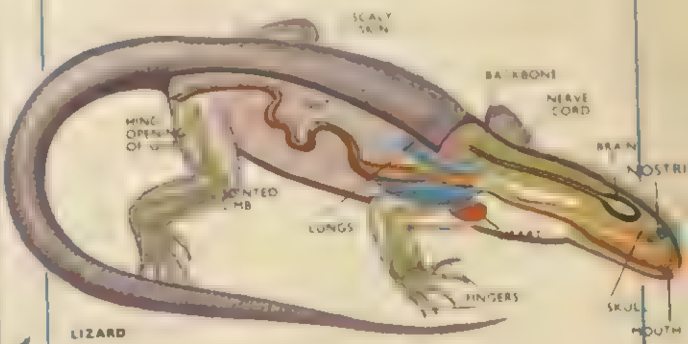
The gar-pike is primitive in appearance – it has a thick covering of scales.



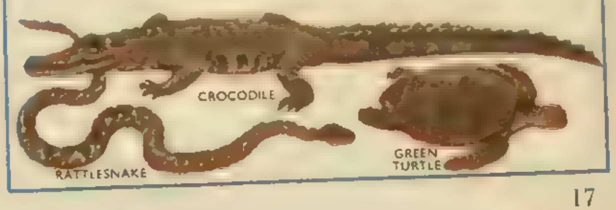
The lung-fishes have a bony internal skeleton. Modern forms have no vertebrae; the notochord is present as a long rod. The paired fins are fleshy. The lungs are divided into pouches. They play an important part in respiration, the blood supply to the gills being reduced. There are internal and external openings to the nostrils. (In the other bony fishes and sharks the nostrils are not in communication with the mouth.)

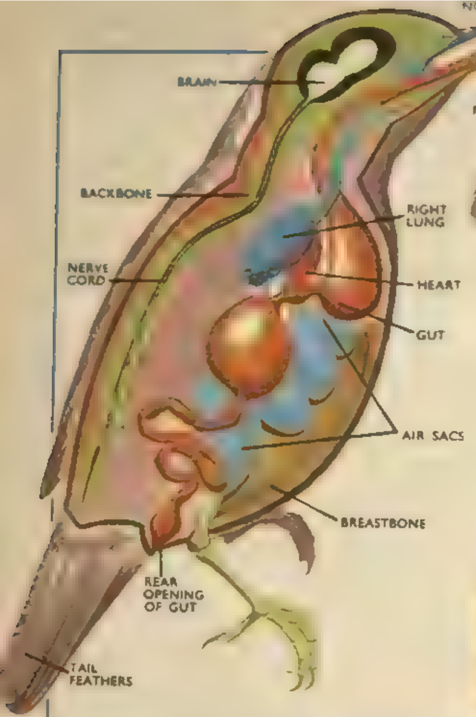


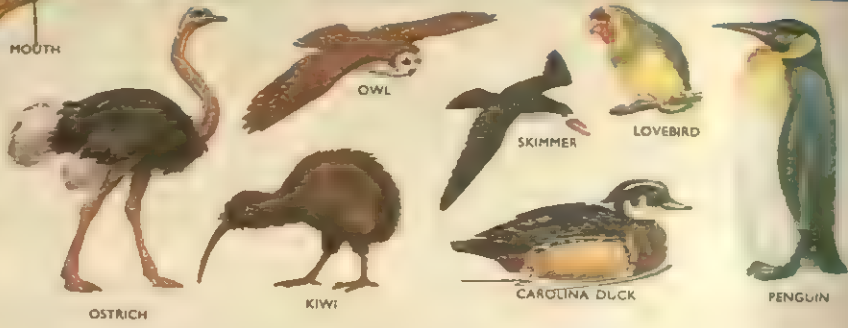
In contrast to fishes, amphibians (e.g. frogs, newts) have a smooth scale-less skin (except for some limbless forms). It is used for respiration. The paired limbs are jointed structures, and though the basic number of fingers is five, many amphibians have less than this. Living on land their body has to be supported (the weight of water-dwelling creatures is supported by the water) and the backbone acts as a girder transmitting the weight to the four legs. When moving quickly, newts wriggle in a way which resembles that of fishes, but slow movement is brought about by the movement of the legs, the body being raised off the ground. In frogs the skeleton and musculature are specialised for jumping and swimming – the number of vertebrae is much reduced. Adult frogs have paired lungs. Only the tadpoles have gills, though some adult salamanders retain their gills.



Reptiles have a scaly skin. The forelimbs are jointed and typically five-fingered (though limbs are absent in snakes). They all breathe air by means of lungs and breed on land, laying shelled eggs (amphibians have to return to water to breed). The head is held off the ground and the neck is better developed than in amphibians, though the basic plan of the skeleton is similar. Ribs are well developed between the shoulder and hip region. Reptiles have more powerful jaws than amphibians.





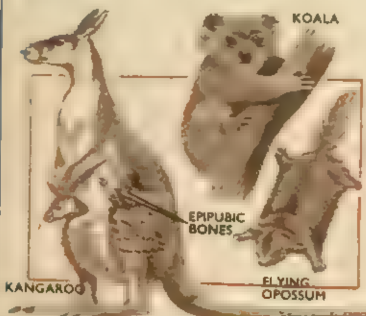


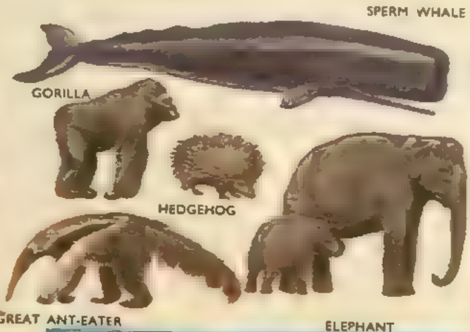
Birds show some reptile characters in having scales on the legs, and in laying shelled eggs. They have feathers and the forelimbs are modified as wings. Birds have no teeth but a horny beak. Many of the bones are hollow to reduce the bird's weight for flying. Ribs form a protective cage round the heart and lungs. There is a well-developed system of air sacs which help provide the large quantities of oxygen needed for flying. The large flight muscles may account for one-fifth of the total body weight and are attached to a large keeled breastbone. The brain is particularly well developed


VARIOUS BEAKS AND FEET

Mammals are the only animals that have hair The bones and muscles of the legs carry the weight of the body, while the backbone is a girder between them from which the gut and other organs hang The rib cage protects the lungs and heart, but an important difference between mammals and birds is the separation of these organs from the organs in the lower part of the body by a thin sheet of muscle – the diaphragm The brain is better developed in mammals than in any other group, allowing for the variety of activities that is characteristic of them.

Most mammals give birth to their young alive; structures occur in the female therefore that are not found in birds The teeth are usually of several kinds – specialised for grinding, tearing flesh and so on.



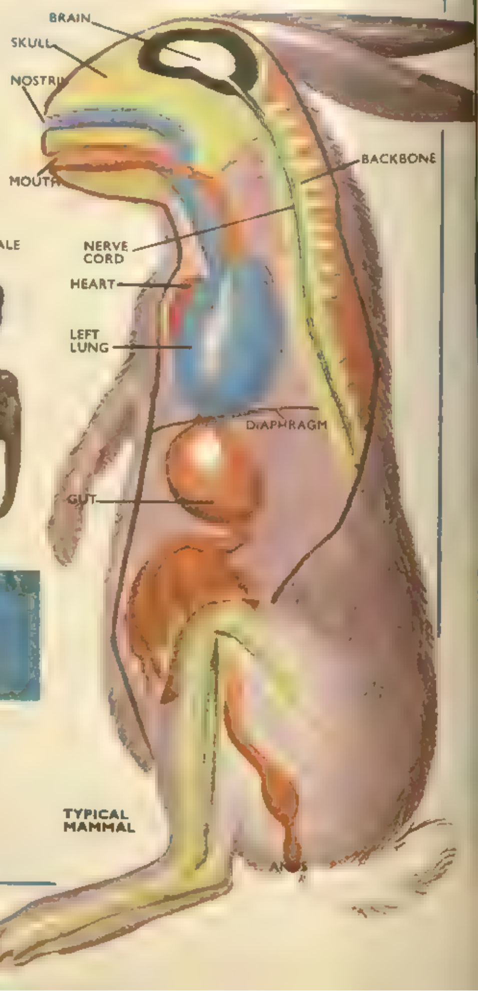


In marsupials the young are born at a very early stage and suckled in a pouch. The latter is supported by the so-called epipubic bones. These are not found in other mammals.

Monotremes lay eggs (in this respect they are like reptiles), but like other mammals they have hair and suckle their young


SKULLS

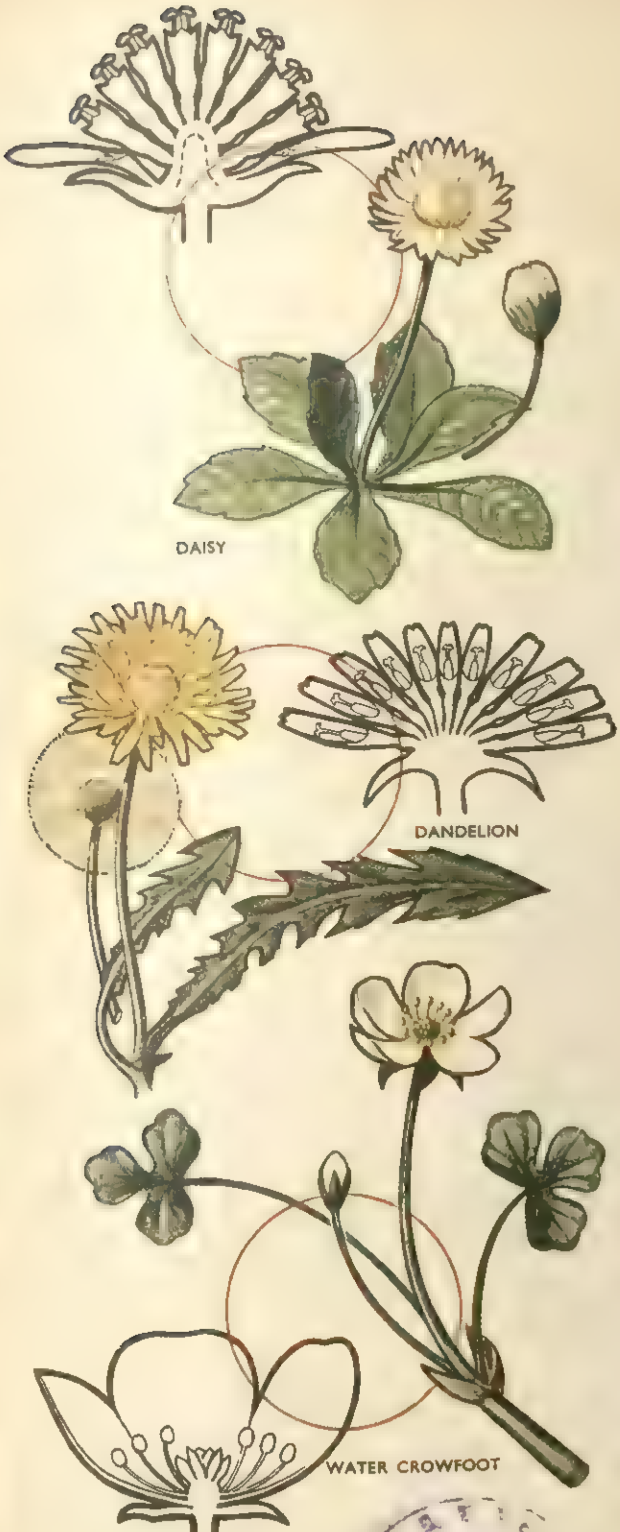

Mammals walk on the soles of their feet (left) or on all their digits (centre) or on one or two (right)



TYPICAL MAMMAL

2. Plant Classification


MARSH MARIGOLD
SWEET PEA
BUTTERCUP
WHITE DEADNETTLE
RUNNER BEAN
WILD OAT
GARDEN SAGE
RYE GRASS
THREE FLOWERS
ARE SHOWN – ONLY
ONE IS OPEN



The Classification of Plants

Look thoroughly at the shoots and half flowers, noting likenesses and differences
1. Place them in groups.
2. Make a list of common characters in each group.
3. Invent a 'key' for identification.

Investigation of variation: Each member of the class could collect 10 plants, say buttercups, and count the parts of the flowers, number of leaves and length of stem. The information could be recorded in the form of histograms.

THERE are nearly 350,000 different kinds or species of plants. No two plants are exactly alike. One fir tree will always differ slightly in shape and height from another, yet two fir trees are more alike than a fir tree and an oak tree. Amongst the many different kinds of plants some are more alike than others. The differences and likenesses are used to place them into groups which may be subdivided many times, the members of a sub-group having more features in common than the members of a group. In a similar way a battalion in the army is divided into companies, a company into platoons and each platoon into sections.

A classification is necessary to describe the relationship of the many kinds of plants.

Besides taking into account the plants living today any system of classification must include plants which are now extinct. From the many fossils that have been found, the ancestry and the relationships of the various plant groups have become much clearer. The plant kingdom may be divided into four main groups: the Thallophyta (algae and fungi), the Bryophyta (mosses and liverworts), the Pteridophyta (ferns and fern-like plants), and the Spermaphyta or seed-bearing plants (i.e. angiosperms or flowering plants and gymnosperms—cone-bearing plants). The buttercups illustrated overleaf show the sort of characteristics on which classification is based.

The different kinds of buttercup all belong to the genus *Ranunculus*. One species is called *Ranunculus repens*, another *Ranunculus acris* and a third *Ranunculus bulbosus*. The Latin names may appear cumbersome and hard to pronounce but they are standard throughout the world. Common names not only vary locally, but from country to country and may be the same for completely different plants in different regions. All the species of the genus *Ranunculus* have certain features in common. The flowers have

CYCADS
CONIFERS
FERNS
GINKGOS
CLUBMOSSES
HORSETAILS
MOSSES
FUNGI
LIVERWORTS
BACTERIA
ALGAE
GYMNOSPERMS
DICOTYLEDONS
MONOCOTYLEDONS
ANGIOSPERMS
THALLOPHYTA
BRYOPHYTA
PTERIDOPHYTA
SPERMAPHYTA

a calyx and a corolla, many stamens, the fruit is made up of many achenes (dry, one-seeded fruits) and each petal has a pocket-like nectary at its base. The species differ in such respects as the shape of the leaves, stems and roots. Closely related genera are grouped into families. For example *Ranunculus*, *Clematis* (e.g. old man's beard), *Caltha* (e.g. marsh marigold) and *Anemone* are grouped in the family Ranunculaceae. Related families are arranged into orders or cohorts. Thus the Ranunculaceae are in the order Ranales and this order, with others, forms the class Dicotyledoneae of the sub-division Angiospermae.

The classification of *Ranunculus repens* may be written:

Division:	Spermaphyta
Sub-division:	Angiospermae
Class:	Dicotyledoneae
Order:	Ranales
Family:	Ranunculaceae
Genus:	Ranunculus
Species:	repens

As the illustration shows, the Angiosperms or flowering plants are divided into two classes, the Monocotyledons and the Dicotyledons. The latter are herbs or woody plants in which the vascular system of the stem forms a ring in cross-section, the young plant in the seed has two cotyledons (seed leaves) and the leaves are net-veined. The flower parts are usually multiples of four or five. The Angiosperms are a sub-division of the Division Spermaphyta, the seed-bearing plants.

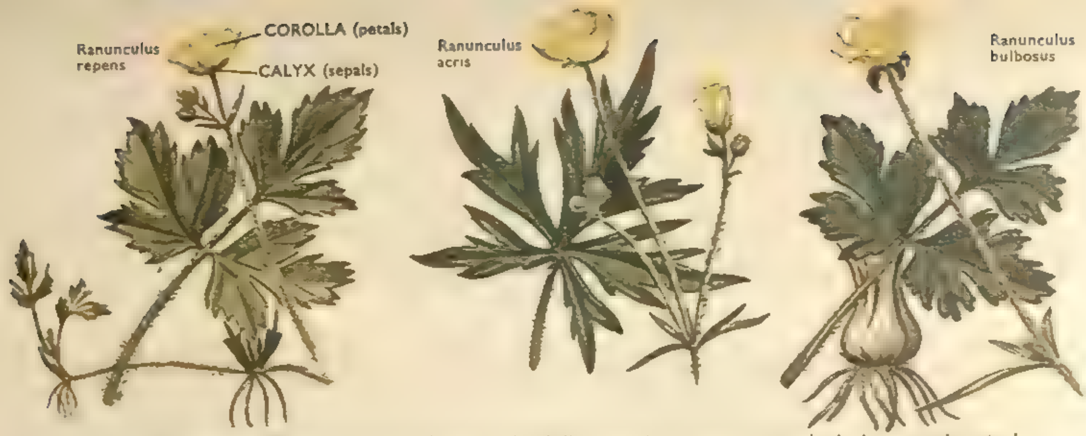
THE MAJOR PLANT GROUPS

THALLOPHYTA

Bacteria—minute single-celled plants, usually colourless, though some may be yellow, red or blue. Largest are only 1/2000 inch in diameter. Each consists of a cell wall inside which is the jelly-like protoplasm called cytoplasm. Particles in this perform the tasks of the nucleus in higher plant and animal cells.

Algae—a large group including types which range from tiny single-celled forms to giant seaweeds. All possess chlorophyll though this may be masked by other pigments as in the brown seaweeds, for example. They have no roots, leaves, flowers or seeds and most live in water.

Fungi—simple plants that lack chlorophyll and so live as parasites on other living things or as saprophytes on decaying plant and animal remains. Generally speaking the 'body' of the fungus consists of a loose network of delicate, branched threads. These may be divided into cells which contain one or two nuclei or may be undivided and contain



Three species of buttercup (Ranunculus) *showing the differences in structure on which they are classified.*

many nuclei. Most fungi reproduce by producing single-celled structures called spores, each of which may grow into a new plant.

BRYOPHYTA

Mosses—small, green plants with a definite stem that bears rows of tiny undivided leaves having no stalks. The leaves have a thickened central region, the midrib. Some mosses grow upright and feathery, others grow flat to the ground. The bottom of the stem usually forms a rhizome on which are small hairs or rhizoids serving as roots. The stem nearly always contains a fluid-conducting strand. Moss plants produce spores in special stalked capsules. The spores sprout and grow into plants which produce male and female organs. The fertilized egg cells grow into new capsules and the cycle is repeated.

Liverworts—small green plants which, like mosses, produce male and female organs in definite parts. The plant body is a flat, leaf-like structure which may be forked many times. Tiny hairs called rhizoids on the underside of this absorb water and anchor the plant. Some 'leafy' types resemble mosses but the leaves are usually divided into lobes. The leaves generally lack a midrib. Life cycle similar to mosses.

PTERIDOPHYTA

Clubmosses—vascular plants with stems, roots and leaves. The vascular system takes the form of a solid cylinder in the centre of the stem made up of alternating bands of food and water-conducting vessels. The leaves are small and clothe the branching stems. Spores are produced in cones which are usually at the tips of the stems. They may be of two kinds (i.e. male and female) or of one kind. In the latter case the young sexual plant which grows from the spore produces male and female cell-producing organs. In the former sperm from the male spores fertilize the egg cells in the female plant and each fertilized structure grows into a spore-forming plant.

Ferns—vascular plants, typically with large divided leaves which bear spore-forming organs. Spores are shed and develop into plants which bear male and female organs. Stem often small and may form an underground rhizome which bears roots.

Horsetails—green, vascular plants. Unlike the clubmosses, they have jointed stems on which the leaves are arranged in whorls at the joints. The part of the stem underground forms a rhizome which bears roots. Certain stems bear cones which produce only one kind of spore. The spores grow into plants which produce male sperm- and female egg-producing organs. The fertilized egg cell grows into a spore-producing plant.

SPERMAPHYTA

Gymnosperms—vascular plants with roots, stems, and leaves that produce seeds in cones. The seeds are naked (i.e. not enclosed in an ovary), unlike those of the Angiosperms or flowering plants. The fertilized female egg cell is retained in the female cone and develops there. The young plant or embryo therefore spends its early development protected and supplied with food by the parent before it is released in the seed

Ginkgos—only present-day survivor of this group is the maidenhair tree. This Gymnosperm differs from Cycads in its tree-like form and does not have the usual type of cone. The seeds are stalked and have a fleshy covering. Its broad leaves are divided into two.

Cycads—Gymnosperms that resemble palm trees and tree ferns. They have a crown of fern-like leaves at the top of the stem which is usually unbranched and may be short, partly above and partly below ground, or may reach a height of thirty feet or more. The stems are vascular and very pithy. Each plant has a tap-root system. Male and female cones are found on separate trees at the top of the stems. Pollen from the male fertilizes the ovules in the female cone. The fertilized ovules form seeds.

Conifers—woody Gymnosperms. The seeds are naked on cones and not enclosed in a seedbox. The leaves are very small and often needlelike. Most conifers are evergreen. They have a well-developed vascular system and all parts contain tubes called resin canals. Male and female cones usually occur on the same plant. Pollen produced in the male cones fertilizes the female ovules which form seeds.

Angiosperms—vascular plants with flowers and fruits as well as roots, stems and leaves. The seeds are formed in seedboxes. The vascular system is better developed than in any other plants.

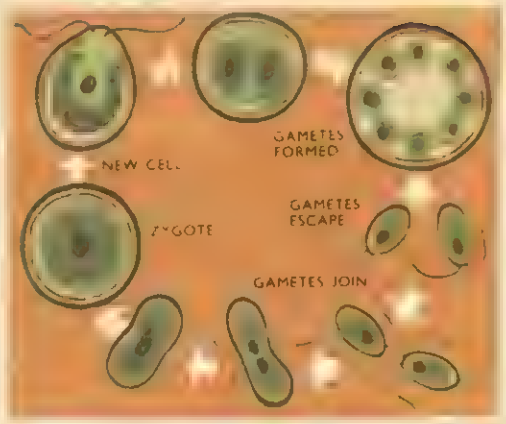
Monocotyledons—Angiosperms in which the leaves are usually parallel-veined, the seeds have one seed leaf (cotyledon) and the veins or vascular system are scattered through the stem. Flower parts generally in threes or multiples of three.

Dicotyledons—Angiosperms in which the leaves are usually net-veined, the seeds have two seed leaves, and the veins form a ring in a cross-section of the stem. Flower parts are generally in four or five or multiples of four or five.

Plants that move about

ALMOST any drop of pond-water, when looked at under the microscope, can be seen to contain hundreds of tiny moving organisms. In spite of their ability to move, most of these organisms are *plants*. They are tiny *Green Algae*—primitive flowerless plants related to seaweeds. The majority of them consist of only a single cell (just like the protozoan animals). The plants contain *chlorophyll* (the green colouring matter) and can make their own food by photosynthesis. Animals cannot do this. The plants also have a cellulose wall.

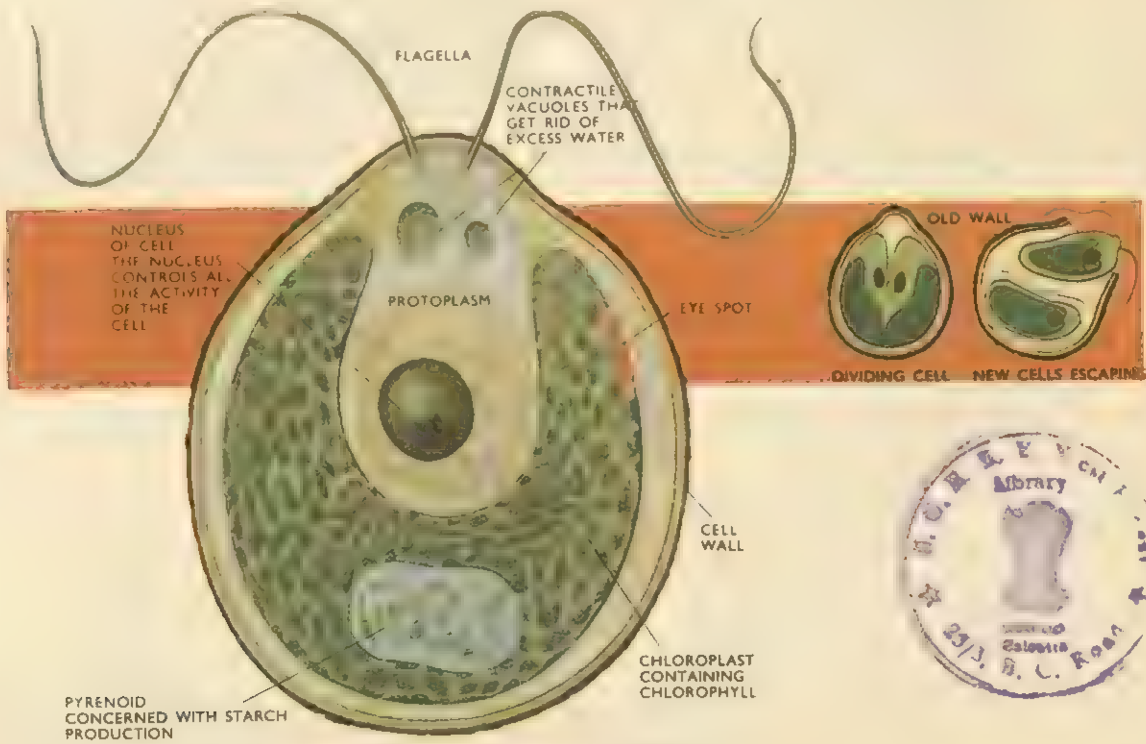
These tiny green plants swim freely near the surface of both fresh and salt waters and are the basic source of food for all life in the water. One of the commonest plants in the freshwater plankton is *Chlamydomonas* (Clam-ee-dom-OWN-ass). Its single oval cell is so tiny that fifty of them would only just



The life cycle of Chlamydomonas *during sexual reproduction.*

An adult Chlamydomonas *plant showing the typical features of this type of alga.*

Chlamydomonas *splits in two at frequent intervals to produce a host of new individuals.*



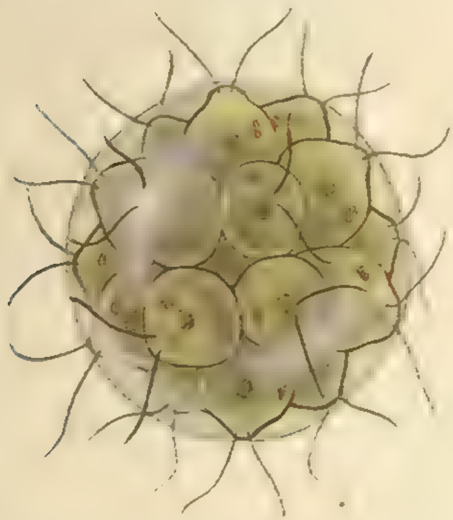
Two groups of single-celled plants that float in fresh and salt water are Diatoms and Desmids.

about stretch across a pin's head. From one end two fine flagella emerge and drive the organism forward as they lash about. There is a large cup-shaped *chloroplast* containing the chlorophyll. A lighter area in the chloroplast is the *pyrenoid* and is concerned with starch production. All the processes in the cell are controlled by the nucleus. There is no problem in getting oxygen for respiration—it just diffuses through the cell wall. The same goes for the carbon dioxide used in photosynthesis.

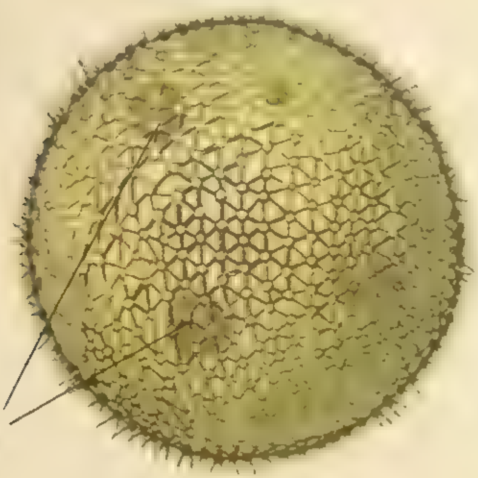
Towards the front of the organism is a red spot. This is the *eye-spot* and is concerned with the detection of light. *Chlamydomonas* is able to respond to light.

When the light and temperature are just right for it, *Chlamydomonas* grows rapidly and each one may split into two or more new individuals every day. Huge numbers of this plant result and, together with other algae, may make the water green. When the cell is about to divide, the flagella are withdrawn and the organism stops swimming. The nucleus, protoplasm and chloroplast all divide once or more and a new cell wall develops around each new group to give two, four or eight new cells. They produce flagella and swim away as new *Chlamydomonas* plants when the cell wall of the parent breaks up.

If the conditions are not favourable (i.e. lack of sunlight and low temperature) *Chlamydomonas* may reproduce in another way. Each one splits up (within its wall) into perhaps sixty-four tiny bodies called *gametes*. When the cell wall bursts, the gametes are released and they join up in pairs (not necessarily from the same parent) to form *zygotes*. The flagella are lost and a thick wall develops. In this state the organism is very resistant to drought and cold. When better conditions return the thick wall breaks down and two or more young individuals are released: the zygote has divided within the resting spore.



Pandorina *(above) is a colonial form of sixteen cells all of which take part in reproduction.* Volvox *colonies (below) are made up of thousands of cells but only a few divide and form new colonies.*

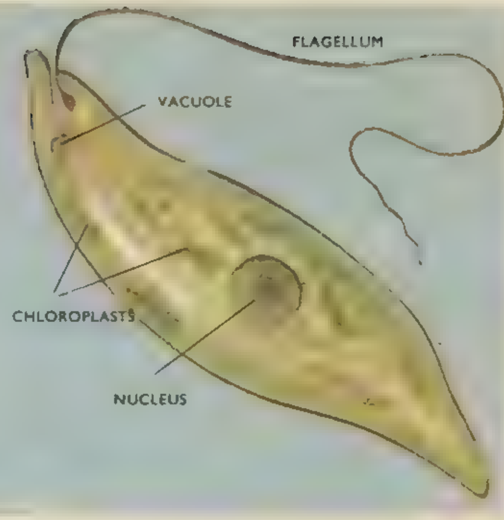


Colonial algae

Chlamydomonas lives by itself—it is a solitary alga—but many of its relatives live in colonies. *Gonium* is a simple colonial form in which about sixteen chlamydomonas-like cells unite to form a flat plate. *Pandorina* colonies also have sixteen cells but here they are arranged in a solid ball embedded in jelly. Each cell has its own flagella on the outside and these move the whole colony, but each cell acts as an individual plant. All the vital functions, such

Euglena

Chlamydomonas is to some extent halfway between animals and plants but *Euglena* (ewe-GLEEN-a) is even more of a puzzle. Botanists claim that it is a plant while zoologists claim it as an animal. It does not have a rigid cell wall like *Chlamydomonas* and it swims by lashing a relatively long flagellum. Some species of *Euglena* contain chloroplasts with chlorophyll and they feed like plants. Others contain no chlorophyll and absorb organic food like animals. Some species even live like plants in the sunlight and like animals in the dark. Some scientists suggest that organisms like *Euglena* were the ancestors of both plants and animals.



as nutrition and reproduction, go on in each cell.

When the colony reproduces, each cell divides into sixteen tiny ones. The cell walls of the parent colony then break down and sixteen new colonies, each of sixteen tiny cells, are released. The colony also reproduces sexually. Each cell produces a number of gametes—there may be sixteen large ones or thirty-two smaller ones. When they are released, they join in pairs (usually one large and one small) and form zygotes. After a period of rest each zygote gives rise to a new sixteen-celled colony.

Volvox colonies are much larger and can just be seen with the naked eye. Each colony is a hollow ball of several thousand cells, but only a few cells are able to reproduce. These cells are usually larger than the rest. They begin to divide when the conditions are right for rapid growth and the bundles of cells fall into the hollow of the parent colony. When the latter breaks up, the new colonies are released into the water.

As in other algae, there is another form of reproduction. Some cells develop into large 'female' cells while others divide into a number of small 'male' cells. When the reproductive cells are released, 'male' and 'female' ones join up and a thick cell-wall develops round them. This resists cold and drought and, when better conditions return, the cell inside divides rapidly to form a new colony which bursts out of the resting spore.

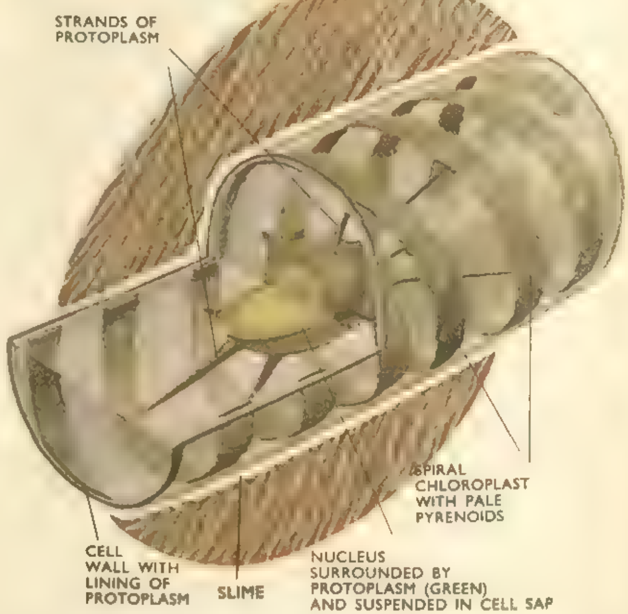
There is in *Volvox* a division of labour between the cells—only some are concerned with reproduction. The difference between the 'male' and 'female' cells is more marked here than in the simpler forms. The more advanced algae, such as *Spirogyra*, may have developed from single-celled forms, through a stage like *Volvox*.

Spirogyra

Few ponds and ditches are without their quota of green scum in spring and summer. A stick dragged along the surface will bring up a slimy mass of green threads. Many of these will belong to a simple plant called *Spirogyra* whose delicate structure is easily seen under the microscope.

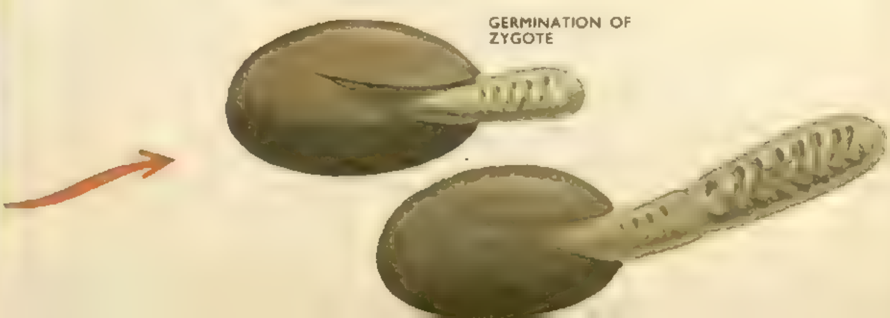
A thread of *Spirogyra* consists of a string of tiny cells surrounded by a layer of mucilage or slime produced by the cells. All of the cells look alike and all of them act as individual organisms. The thread can be broken into many pieces and each will continue to live and grow. No cell has any special function such as is found in higher plants and animals.

The most noticeable feature of the cell is the spiral chloroplast containing the green chlorophyll. There may be more than one chloroplast and their shapes may help to identify the various species. Embedded in the chloroplast are numerous paler regions called pyrenoids. These seem to be concerned with starch production. The cellulose cell-walls are lined with



Spirogyra *is frequently brought up by fishing lines and nets. The strands and individual cells are shown enlarged.*

Diagram of stages of conjugation between cells of neighbouring strands. The protoplasm of one strand (the 'male') passes across into the other (the 'female'). Cells of a single strand will be all male or female.



protoplasm surrounding a space or vacuole. In the centre of this space is the nucleus, suspended by strands of protoplasm. Each cell manufactures its own food from mineral salts, water and carbon dioxide and is quite independent of its neighbours.

Reproduction

When the water is warm and there is plenty of mineral food and sunlight, the cells grow rapidly and divide at frequent intervals. The chain of cells lengthens rapidly. It often breaks and each fragment quickly grows into a new chain. In this way large masses of the plant soon accumulate.

Under less favourable conditions—for example in the autumn when the water cools down, or during drought—*Spirogyra* reproduces in another way. Two neighbouring threads that lie close together produce tiny projections that grow out towards the adjacent cells. The projections join and form a tube linking the two cells. By this time, the contents of the cells have shrunk and the chloroplast has broken up. The cell contents of one thread move across into the cells of the other thread where they join with the other protoplasm. A thick wall forms round the joined protoplasm which is then called a zygospore. This type of reproduction is called conjugation.

The zygospore is released when the old cell wall breaks up. It may rest at the bottom of the pond or be whisked away by the wind until it finds suitable conditions for growth. These tiny spores are very resistant to drought and cold and can probably remain alive for years. They are responsible for the sudden appearance of *Spirogyra* in artificial ponds and fish tanks. When they reach suitable sites, the spores germinate and grow into new threads.

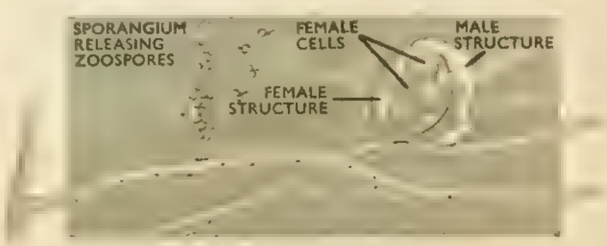
Plants that need no sunlight

THE green mould on the top of cheese, the wispy growths on stale bread, and the brightly coloured toadstools of the woods may not appear to have much in common, but all are members of the plant group called *Fungi*. The body of a fungus normally consists of fine threads *(hyphae)*. Chlorophyll is completely absent from fungi and they cannot therefore manufacture food from the carbon dioxide and water in their surroundings as normal plants do. They are not capable of photosynthesis and not dependent upon sunlight. Many of them live in complete darkness. They must rely for food on ready-made organic matter which is absorbed by the threads from the material on which they grow. In this respect fungi resemble animals, which also need ready-made food. The threads often release digestive juices which liquefy the food material. Many of the fungi are *parasites*, absorbing food from living organisms. Those which exist on dead material—leaves, twigs, leather, etc.—are called *saprophytes*. They play an important part in the economy of nature for they break down dead organisms and release material for use by other plants.

As food and water are absorbed, the threads of the fungus increase in length and frequently branch. Growth is far less complicated than in the higher plants for there are no special tissues in the fungi. The threads are simple tubular structures whose wall consists of various types of cellulose and nitrogen compounds. They contain protoplasm, nuclei and droplets of oil which act as food reserves. Pigments occur in the coloured varieties. The threads are sometimes divided by cross-walls into cells, each with one or two nuclei.

Fungi are classified according to their structure and the way in which they reproduce. There are three major groups.

Saprolegnia *exists on dead organisms in water. It reproduces itself by mobile zoospores (left) and by fusion of male and female structures (right).*



Glossary

Hyphae: the threads of a fungus.

Zoospore: a tiny, single-celled body produced in the swollen tips of fungal threads, which can escape and grow into a new thread. In those species that live in wet surroundings the zoospores may have flagella.

Sporangium: the swollen tip of a thread producing the zoospores.

Oospore: the resting spore produced after male and female cells have joined together. There is one diploid nucleus.

Zygospore: the resting spore produced after the fusion of branches of plus and minus threads. There are many diploid nuclei.

Diploid: a diploid nucleus has two sets of chromosomes.

Haploid: a haploid nucleus has only one set of chromosomes.

Meiosis: the division of a diploid nucleus to give haploid nuclei.

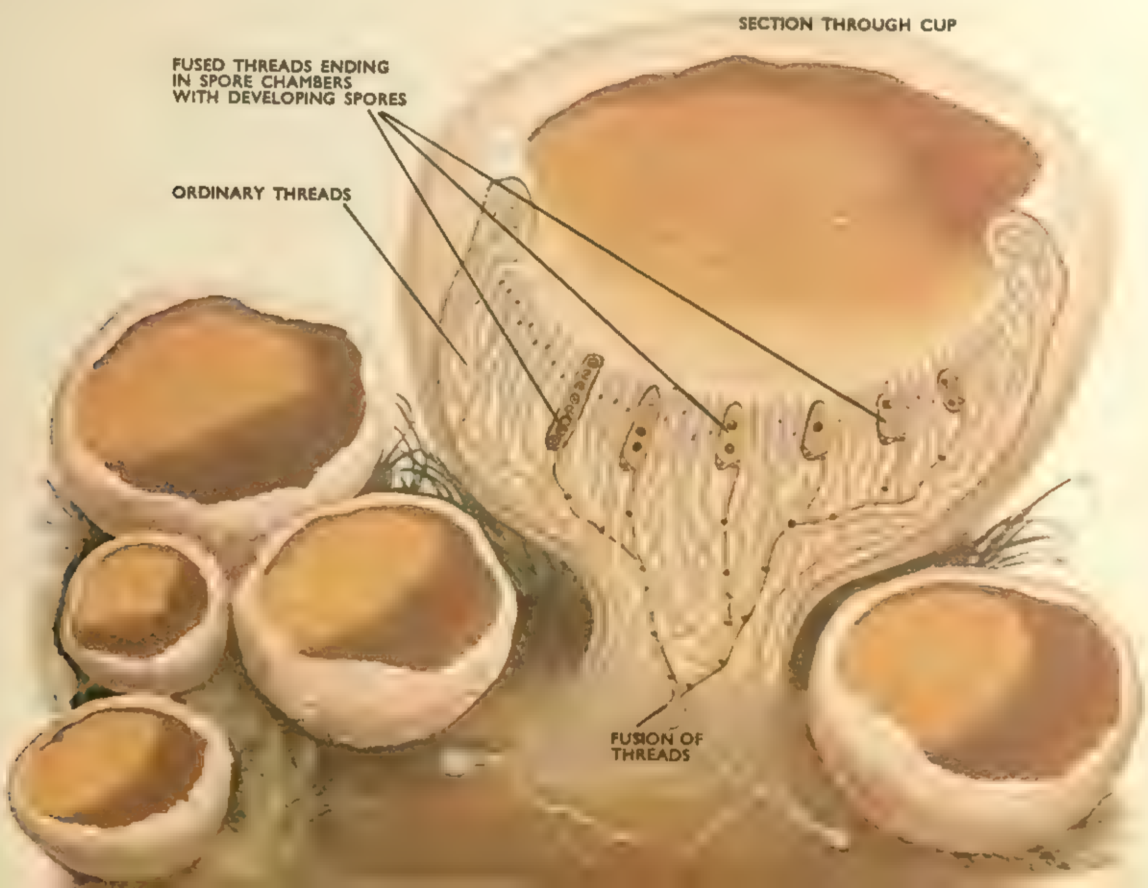
Chromosomes: thread-shaped structures occurring in pairs in the nuclei of nearly all cells. Nuclei of gametes have unpaired chromosomes.

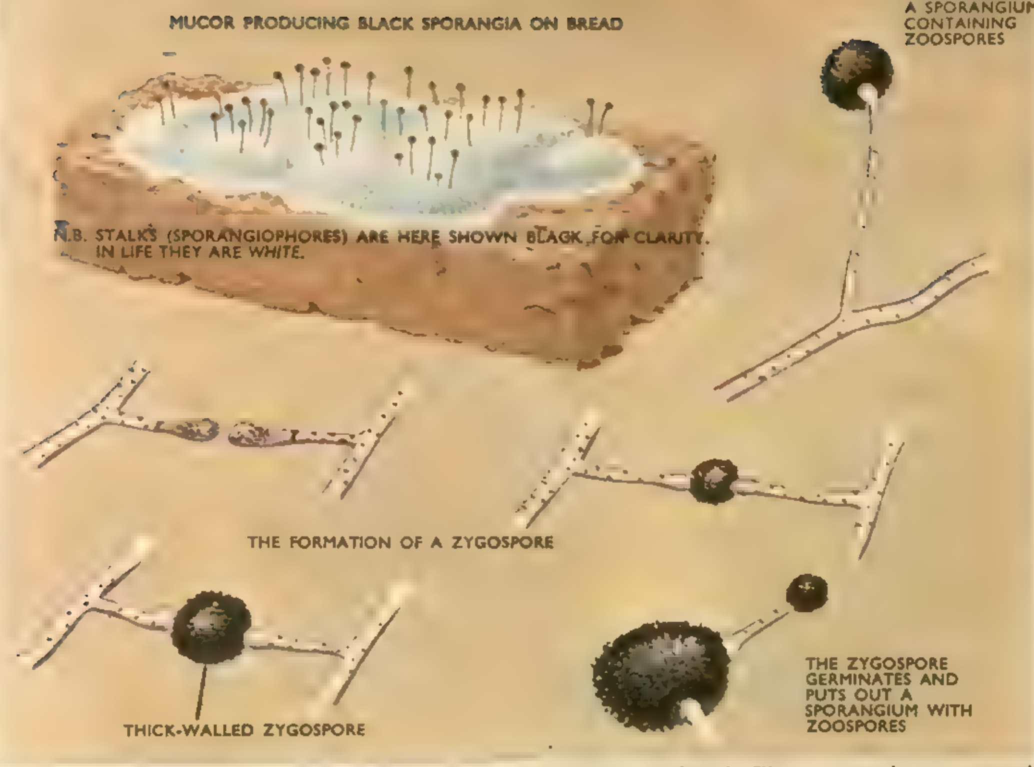
Phycomycetes

The threads of these fungi are not divided up into separate cells. Many of the species live in water or are parasites of flowering plants.

Saprolegnia lives in water where its white threads are common on dead twigs, insects and even on injured fishes. The threads branch over and through the tissues and frequently swell at the tips. The swollen tips *(sporangia)*, containing many nuclei, are partitioned off from the rest of the thread by a wall. Each nucleus becomes associated with a piece of protoplasm which rounds off and produces two whip-like flagella. The tip of the thread opens and the tiny bodies swim away by means of their flagella. Actively swimming bodies like this are common among lower plants. They are called *zoospores.* Each zoospore, if it reaches a suitable place, grows into a thread of fungus. Because of the large number produced, it is rare for a single zoospore to develop alone—there are usually a number of others close at hand. The zoospores are thus agents of *asexual* or *vegetative* reproduction.

Cup-fungi such as Peziza *are ascomycetes. The fruiting bodies develop after two threads have joined. Spores develop in the fruiting bodies in special cells called* asci.





Mucor *grows on many materials such as stale bread where it forms a fluffy mass of threads. The non-sexual spore-containing organs* (sporangia) *are black and release air-borne spores. When threads fuse they form* zygospores *which are very resistant. The zygospore germinates and produces a sporangium.*

Saprolegnia has another method of reproducing itself, especially towards the end of its life. Tips of branch-threads swell up and become partitioned off. There are two types of swelling—usually close together. The larger one is the female structure whose nuclei and protoplasm form sex-cells. The male structure is club-shaped and grows into contact with the female structure. The male cells then pass into the female structure and join with the female sex-cells forming a number of *oospores* or *'eggs'*. The nuclei join together and a hard wall forms round the 'egg'. It can resist bad conditions such as drought and then, after division by meiosis, which reduces the chromosome number, it puts out a new thread with a single set of chromosomes in the nuclei.

Mucor—the common Pin Mould of bread, leather, etc.—is another member of this group of fungi but differs in two important ways. The asexual zoospores have no flagella; they would be unsuited to the drier conditions under which *Mucor* lives. The spores are distributed by wind or by insects. There are no distinct male and female structures but not all the threads act alike. There are two physiologically different strains (called *plus* and *minus*) and when the two meet they form reproductive structures. The occurrence of two physiologically different strains is called *heterothallism* and is found in most of the higher fungi.

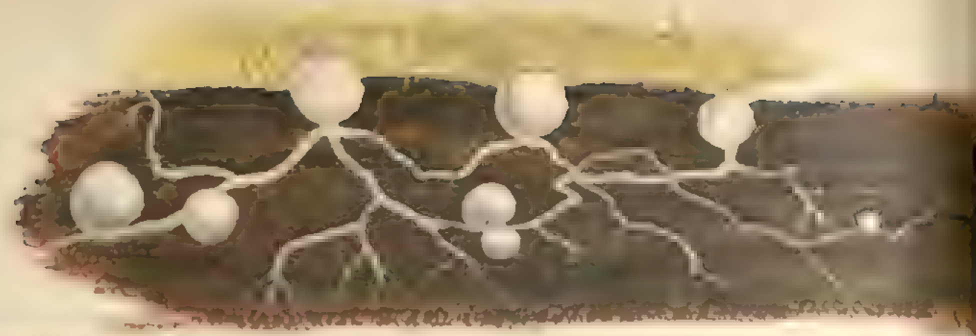
In *Mucor*, the tips of side-threads are partitioned off and those of opposite strains join together. The nuclei join in pairs and a hard wall forms around them. This is the *zygospore*, corresponding to the 'egg' of *Saprolegnia*. When the zygospore germinates, it puts out a single thread which bears zoospores at its tip. These are distributed and form new threads.

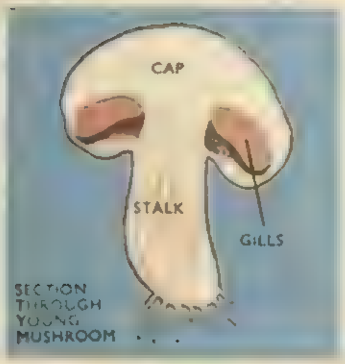
The ascus formers

The threads of these fungi are divided into 'cells' each with, normally, a single nucleus. Many are important parasites but the most obvious are the brightly coloured cup-fungi, such as *Peziza*, which live on dead logs and the like. The sexual spores are formed inside special cells called *asci* (singular ascus) which normally occur in 'fruiting bodies' made up of masses of tightly packed threads. The fruiting bodies are often brightly coloured.

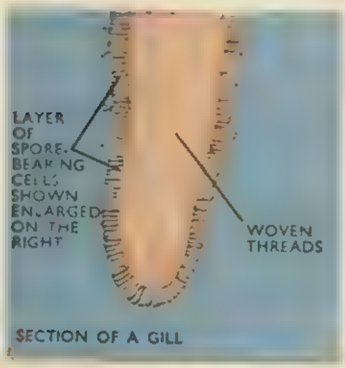
The basidium formers

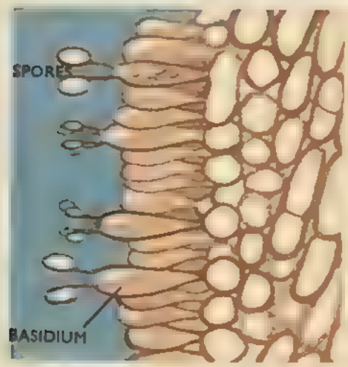
To this group belong the most familiar fungi—the mushrooms and toadstools. Their early life is much like that of the previous group—they exist



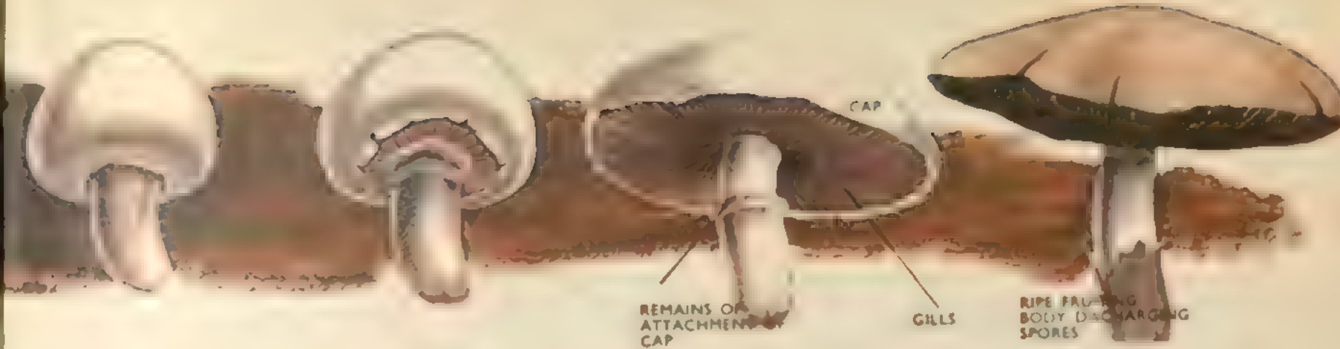


The common mushroom starts life as a single thread which branches and eventually joins with another. The fruiting bodies develop from knots of threads and then, when nearly complete, they grow rapidly by absorbing water. The cap breaks away from the stalk and exposes the gills which are shown in greater detail at left.





SOME BASIDIOMYCETES AND ASCOMYCETES



as fine branching threads on dead leaves, manure, etc. When threads of opposite type meet, they again produce fruiting bodies of closely matted threads, some of which have two nuclei in their cells. The fruiting body of the mushroom develops underground as a small knot of threads. Its structure is almost fully formed before it appears above ground, and then, by absorbing large amounts of water, it grows up into the air and opens out into the typical umbrella-shape. On the underside of the cap there are many radiating gills which bear the spores. The threads bear club-shaped cells at the tip and in these cells *(basidia)* the two nuclei fuse. They then divide and four new nuclei pass into four tiny swellings on the outer end of the cell. These are the tiny spores *(basidiospores)*. They fall when ripe and are distributed by wind.

Some other fungi of this group have numerous pores on the underside instead of gills. The spores are produced on the linings of the pores in these cases. Many of the bracket fungi on trees are of this type.

Liverworts and Mosses

THESE plants, so common in damp, shady places, are of little economic value but are scientifically interesting because many of their characters are halfway between those of the water-living algae and those of the higher land-plants such as ferns. It is probable that the first land-plants were something like the present-day liverworts.

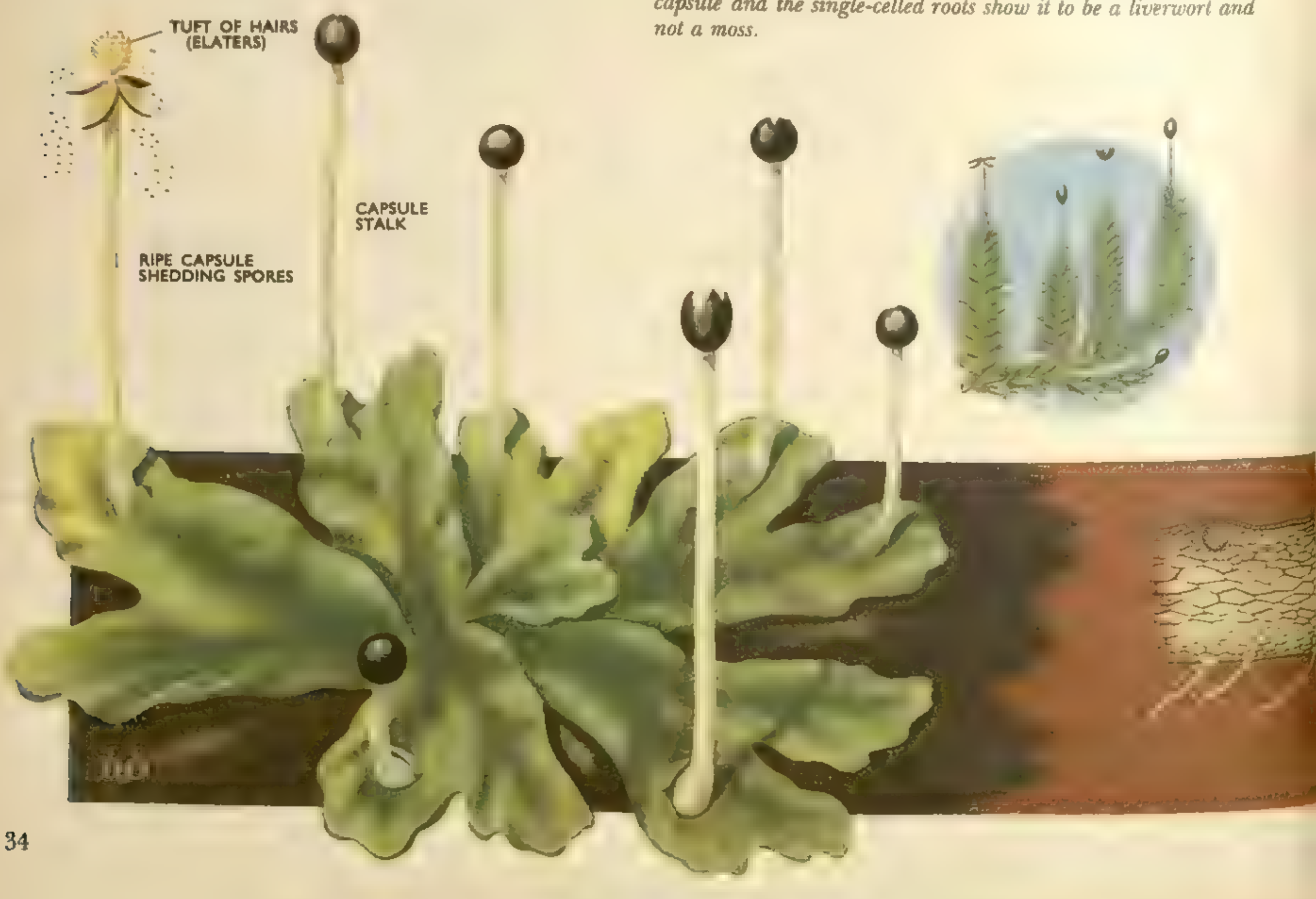
Pellia is one of the simplest and most easily-studied of *liverworts*. The plant is flat and leaf-like and grows close to the soil. It is very common in ditches and on river banks, and can be grown easily in wet soil at home. The cells of the body are all alike except that some central ones are longer and serve to distribute water through the plant. There are no specialized tissues such as are found in higher plants. Most of the cells contain chlorophyll, enabling the plant to manufacture its own food from carbon dioxide and water. The latter is absorbed through the under-surface of the plant which is provided with numerous single-celled 'roots'. The liverwort covers a large area of ground by branching.

Male cells develop in spring in pits on the upper surface and produce a number of flagellated sex-cells (gametes). The female organs arise in groups, covered by a flap of tissue, towards the tip of the branches. Each female organ is flask-shaped and contains a female-cell, and a number of other cells in the neck region. The neck is closed by a cap at first. When the egg-cell is ripe and there is plenty of moisture, the cells in the neck region break down into a jelly which absorbs water and forces the cap off. The male-cells swim freely in the film of water on the plant and are chemically attracted by the jelly of the female organ. One male-cell eventually joins with the female cell.

Three regions soon become visible in the embryo: the *foot*, embedded in the base of the female organ, the *capsule*, and a short *stalk* between the two. The whole is surrounded by the enlarged base of the

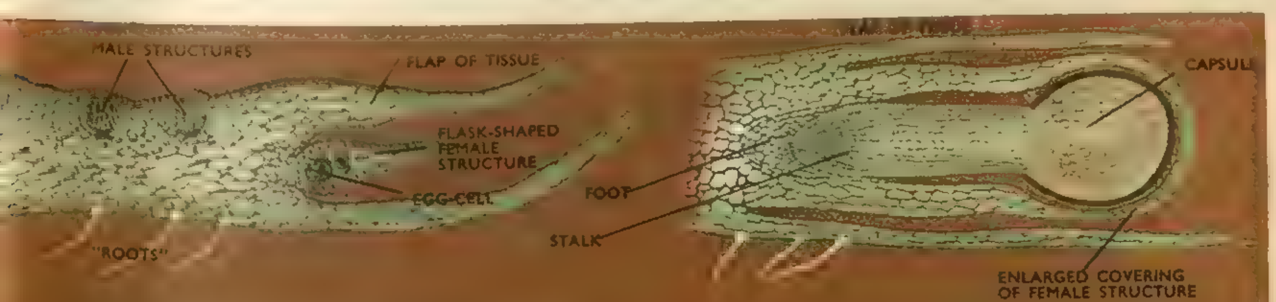
Pellia *is a common flat* (thalloid) *liverwort. The spore-capsules mature in spring and release tiny spores which develop into new plants.*

Lophocolea *is a moss-like, leafy liverwort. The simple spore-capsule and the single-celled roots show it to be a liverwort and not a moss.*



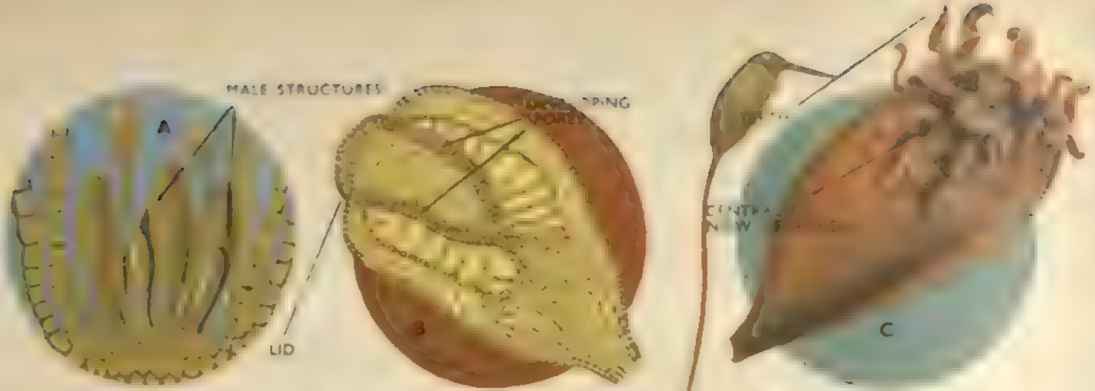
Marchantia *is a rather special flat liverwort. Male and female organs arise on separate plants. They are carried on stalked bodies above the rest of the plant. Male-cells swim in the water film and reach the flask-shaped female organs. The spore capsule develops on the underside of the 'umbrella' and has only a short stalk.*

female organ. Within the capsule numerous individual cells develop. Some are long and slender and are called *elaters*. In the spring—about a year after fertilization—the stalk grows rapidly and exposes the black capsule to the air. The walls of the capsule split and release the spores. Distribution is aided by the slender elaters. These are water sensitive, and as they dry in the air, they twist and scatter the spores. By the time they are distributed, the spores have usually begun to divide, and when they reach a suitable site they develop into new *Pellia* plants.



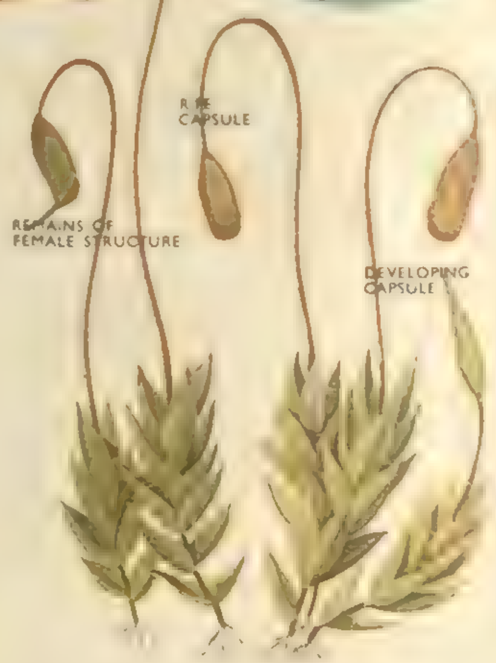
The flask-shaped female organs develop under flaps of tissue towards the tip. The female cell is fertilized by male-cells released from the male organs on the plant surface.

After fertilization the female organ swells and the embryo inside produces the spore-capsule, its stalk and foot. This *sporophyte* generation matures after about a year.

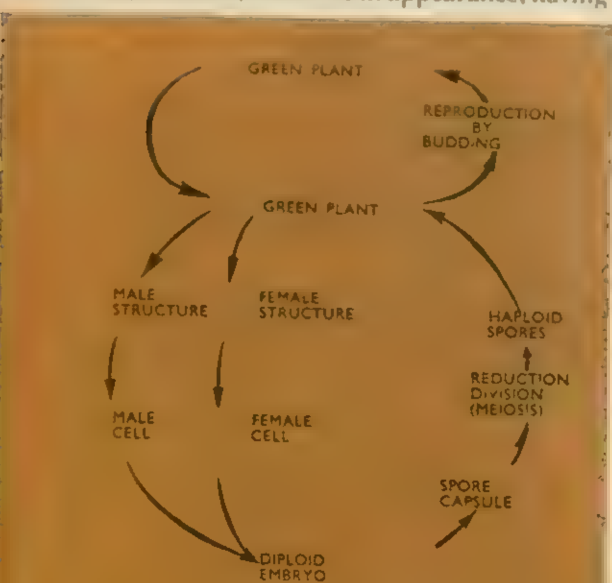


There are, in the life-cycle, two distinct stages the green gamete-producing plant, and the spore-producing body. The occurrence of the two distinct stages in the life-cycle is called the *'alternation of generations'*. In *Pellia*, the sporophyte lives parasitically on the green gametophyte plant, absorbing food through the foot. The alternation of generations can be followed in all the higher plants although the gametophyte is very small.

There are many variations of the characters described for *Pellia*. Many species reproduce vegetatively by means of detachable buds *(gemmae)* which develop in cup-shaped pits on the plant. They are distributed, presumably by water splashes, and grow directly into new plants. The liverwort *Marchantia* produces its sex-organs on stalked structures above the body of the plant. Male and female organs occur on different plants. The majority of the liverworts are, however, moss-like in appearance, having



The moss, Funaria, *is common on burnt ground. Male and female organs occur at the tips of separate branches (A). After fertilization the spore-capsules develop. The spores develop inside the capsule (shown in section at B), and when ripe are discharged through the opening. A series of water-sensitive teeth (C) control the opening of the capsule so that spores are shed only in dry weather.*



The life-cycle of a typical Bryophyte.

Moss spores develop first into a branched thread—the protonema*—from which several individual moss plants develop.*

a stem and leaves. They are classed as liverworts because the capsule normally contains the long elater cells and only appears for a short time.

Mosses have a very much wider range than the liverworts and can be found in all but the driest places. The life-cycle is similar to that of *Pellia*, with a marked alternation of generations. *Funaria* is a typical moss, commonly found growing on burnt ground. The plant body is the haploid stage and carries the sex-organs. There are distinct stems and leaves. The latter are only one cell thick except in the middle. They contain numerous chloroplasts for manufacturing food by photosynthesis. The outer region of the stem is also green. In the centre of the stem there are longer, water-conducting cells. From the lower parts of the stem a number of many-celled 'roots' arise. They fix the plant in the soil and absorb water and salts.

The sex-organs arise at the tips of the stem and branches, and are surrounded by leaves. Male organs are club-shaped while the female ones are again flask-shaped. Male-cells are released in damp conditions and fertilize the egg-cells as in *Pellia*. The resulting embryos develop into the spore-bearing bodies. The lower part of the embryo (the *foot*) embeds in the tissue of the moss while the upper end grows. Soon a swelling appears at the top end; this develops into the spore-chamber or *capsule*. The latter is green and is able to carry out photosynthesis. It requires only water and salts from the haploid plant and is thus more independent than the sporophyte of the liverworts. Capsules are found at all stages of development during the summer. The capsule is far more complicated than that of the liverwort.

When a moss spore falls on suitable ground it puts out a tiny thread at each end. One thread develops into a fine 'root' and the other, which is green, branches over the surface. It is called a *protonema*. From various points on this thread new haploid moss plants arise. The protonema may live for some time and produce numerous plants in a small area. It is not found in liverworts. New threads can be produced at any time from the base of the moss. Buds arise on these and grow into new plants. By this means, mosses reproduce vegetatively and cover large areas of ground. The clumping habit is also important, for the clumps can hold a considerable amount of water. Single plants would rapidly wither if exposed to dry air.

Glossary

Spore: a tiny single celled body produced asexually from the diploid generation after meiosis

Diploid: having two sets of chromosomes in the nucleus.

Haploid: having one set of chromosomes in the nucleus.

Meiosis: a division of the diploid nucleus into four haploid nuclei.

Sporophyte: the generation that bears spores.

Gametophyte: the generation that bears the sex-cells (gametes). This is the actual moss or liverwort plant.

Elaters: slender cells that aid the dispersal of liverwort spores

Chromosomes: thread-shaped structures occurring in pairs in the nuclei of nearly all cells. Nuclei of gametes have unpaired chromosomes.

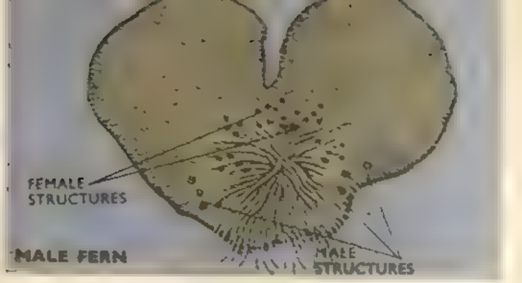
Ferns

TOGETHER with the club-mosses and horsetails, the ferns *(Filicales)* belong to the group of plants called *Pteridophyta* (Terrid-o-figh-ta), which also includes some of the older known land-plants—fossils of the Devonian period. There are, in most ferns, a distinct root, stem and leaf. There is also a complicated network of conducting tissues through which water and food materials move within the plant. This is a definite advance on the stage reached by mosses and liverworts.

Except in the tropical and sub-tropical tree-ferns, that may reach a height of 60 ft. or more, the stem is small and usually remains underground. It is normally unbranched but in some species, for example, Bracken, it is a branching *rhizome* (underground stem) which throws up new leaves from all its branches. It is this feature that makes Bracken such an invasive plant. Fern leaves *(fronds)* are usually large and subdivided into many smaller lobes (e.g. Bracken) though the leaves of the Hart's Tongue Fern are *entire* (undivided). Between the two there is a wide variation in the degree of leaf-division. Roots arise on the stem and on the bases of the leaves. They are all *adventitious* (i.e. they are not branches of the original root). There are *no* flowers.

This brief account is not the complete description of a fern, however, for there are two distinct stages

The spore capsules and their protective flaps in section. The thickened cells of the capsules are water-sensitive.



A prothallus seen from below. The sexual structures develop among the 'roots' of the prothallus.

in its life history—the fern shows *'alternation of generations'*. So far only the spore-forming generations have been described. Each spore develops into a gamete-producing plant. The latter is small and inconspicuous and normally short-lived. This is the reverse of the conditions in mosses and liverworts, where the sporophyte (spore capsule) is short-lived and the main plant is the sexual stage.

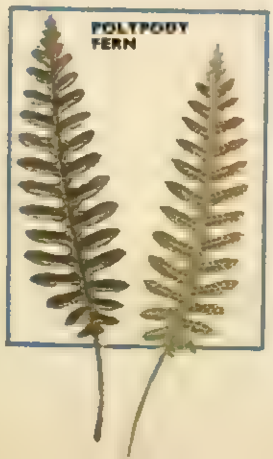
The life-history of the fern is best studied by taking a common example. *Dryopteris felix-mas*, the

The Male Fern puts up a crown of large fronds each year from a short underground stem. Each leaf bears numerous groups of spore capsules on its lower side.

Male Fern, is widely distributed in the northern temperate regions and extends also into Africa and India. It inhabits hedgerows, woodland, riverside and heathland. The stem is a stocky underground structure that puts up a crown of tall leaves (up to four feet) each year. The leaves take two years or more to develop and the following year's leaves can be seen tightly coiled at the top of the stem. As with most ferns, the leaves unroll from the base and are at first covered with brown 'fur'. When they wither, their bases remain attached to the stem which thus appears to get thicker each year.

On the underside of the mature leaf there appear numerous brownish patches, in two rows on each leaf division. If examined in detail, the patches will be seen to consist of stalked swellings, covered by an umbrella-shaped flap. The stalked swellings are spore-capsules and each group is called a *sorus* (plural *sori*). The shape and arrangement of these groups differ from one species to another. In the Hart's Tongue they are in parallel strips, protected by two flaps of tissue. The sori of Bracken are arranged around the edges of the leaf segments and are protected by an incurling of the leaf. In some species there is no covering for the spore-capsules.

The groups of spore-capsules normally occur on ordinary leaves but some species (e.g. Hard Fern) have two distinct types of leaf, only one of which is concerned with producing spores. The Royal



The female cell in its flask-shaped structure (a) is fertilized by the freely moving male cell (b) which is released in wet conditions from the male structure (c).

Fern produces spores only on the terminal parts of its fronds.

Inside the spore capsules the cells undergo division to form spores. When the spores are ripe, the protective flaps wither and the capsules split, releasing clouds of tiny spores. These are very resistant to drought and require plenty of moisture before they will germinate.

Each spore develops into a tiny plate of green cells. This is the sexual generation *(gametophyte)*, also called the *prothallus*. It is similar in most ferns, being heart-shaped and bearing a number of 'roots' on the underside. The sexual structures develop on the underside too. As a rule, structures of both sexes occur on the prothallus but a few species have two types of prothallus (and therefore two types of spore). Male structures are spherical and the female ones are flask-shaped. When the female cell is ripe and there is plenty of moisture, the 'flask' opens and exudes a slimy liquid. This attracts the male cells which are also liberated when it is wet. They are active bodies, swimming by means of flagella. The male cells fuse with female cells and form *embryos*—the beginning of the next sporophyte generation.

The embryo develops at the expense of the prothallus just as the moss sporophyte develops on the green gametophyte. Soon, however, the young fern plant forms its own leaves and becomes self-supporting. The prothallus quickly withers. The young fern leaves are usually very unlike the later ones, being small and relatively undivided. The later leaves become progressively more divided until the mature stage is reached. Then spores are again formed and another haploid generation arises.

Glossary

Alternation of Generations: the existence of two distinct stages in the life-history, one of which is haploid, and the other diploid. It occurs in most plants but is only obvious in some such as mosses and ferns.

Chromosomes: thread-shaped structures occurring in pairs in the nuclei of nearly all cells. Nuclei of gametes have unpaired chromosomes.

Diploid: having two sets of chromosomes per cell.

Haploid: having one set of chromosomes per cell.

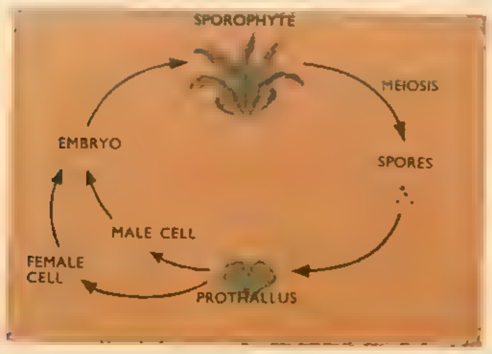
Gametophyte: the generation bearing the sexual structures.

Prothallus: the gametophyte of a fern.

Sorus: the name given to a group of spore capsules on a fern leaf.

Spores: the tiny bodies by which ferns and other lowly plants disperse themselves.

Sporophyte: the generation that bears spores.



The Cone Bearers

FOSSILISED plant remains from various parts of the world show that even before Carboniferous times (nearly 300 million years ago) a number of fern-like plants were producing seeds. They retained the female spore on the parent until after the female cell had been fertilized. The embryo and its protective covering was released as a *seed*. The seeds were borne on the edges of normal or slightly modified, fern-like leaves. These 'seed-ferns' were very common during the time that the coal measures were formed but then became rare and disappeared. Similar plants must, however, have been ancestral to the modern seed-bearing plants—the conifers and the flowering plants.

Although modern conifers such as the pine and spruce, with their large woody trunks, small leaves and seeds always in cones, are far removed from their fern-like ancestors, there is a group of plants that shows many intermediate characters. These plants are the *Cycads* of which there are several genera in tropical and sub-tropical regions. The stem is stout and unbranched and carries a crown of large divided leaves, giving the plant a palm-like appearance. The ovules and pollen sacs develop on special leaves *(sporophylls)* that are scale-like and grouped into cones, just as in the Pine. In the genus *Cycas*, however, the female sporophylls are more leaf-like. Male and female cones grow on separate plants. The male cells released from the pollen grains after pollination have flagella and actively 'swim' towards the female cell. This, and other primitive features, are lost in the true conifers such as the Pine.

Cycads and conifers are just two of the sub-groups of the group of seed-plants called *Gymnosperms*. Other members include the Yew, Japanese Maidenhair Tree *(Ginkgo)*, and various fossil groups. They are distinguished from the flowering plants (Angiosperms) because the seeds are not enclosed in a fruit.

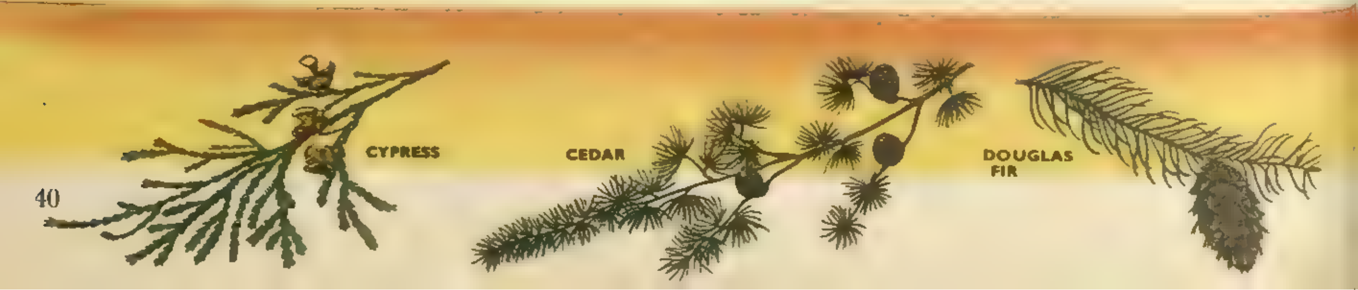
The true conifers are all trees. There is a much greater development of woody tissue than in the cycads. Conifers make up an important part of the vegetation of the cooler parts of the world. Although there is some variation in the form of the leaves and shoots, the important features of the conifers can be observed by studying the Pine *(Pinus sylvestris)*.

The young pine has a somewhat conical shape but as it grows old many of the lower branches are lost and the shape is destroyed. There are two types of leaf: small brown scale leaves, and the green 'needles'. The latter are formed only on dwarf side-shoots (spurs), never on the main shoots or branches. The dwarf shoots arise in the axils of scale-leaves on the main shoots. The needles contain a great deal of strengthening tissue and are able to withstand very cold and dry conditions. The spurs and their needles last only a few years but they are not shed all at once as are the leaves of deciduous trees. The tree is thus evergreen.

The overall structure of the stem is much the same as in the flowering plants but the detailed structure of the tissues varies. There are no long xylem conducting vessels. The root system is normally a tap-root with branches. Root hairs are not well developed but there is a close relationship with a fungus which helps in the absorption of water.

Male and female cones are formed on one tree. Clusters of male cones develop in spring at the base of young shoots. Above the cones, the shoots bear spurs. Each male cone consists of a central stem and numerous spirally arranged scales. Each scale carries two pollen sacs on its lower surface. Attached to the pollen grains are tiny air-sacs which aid in wind dispersal.

The female cones first appear at the ends of some of the young shoots, as small red erect structures. A number of tiny *bract scales* are arranged spirally round the axis, and on each bract scale there is a large *ovuliferous scale* which carries two *ovules*. Each ovule consists of a mass of tissue (the *nucellus*) surrounded by a covering *(the integument)*. One of the cells of the nucellus divides a number of times and then forms four spores. Only one survives and is called the *embryo-sac*. At about this stage (May



or June in the Northern Hemisphere) the female cones are pollinated. The scales separate and pollen from the male cones can enter and reach the ovule.

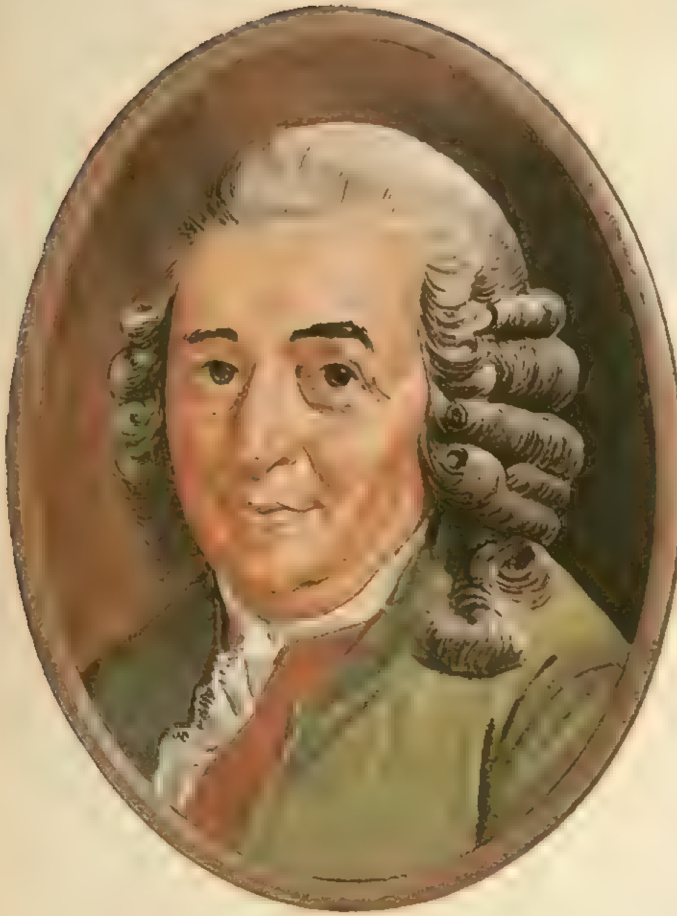
After pollination the scales close up and the cone stalk bends over so that the cone hangs among the needles. The pollen grain reaches the nucellus via the micropyle and a *pollen tube* grows into the nucellus. Development of the pollen grain then stops for about a year in the Pine, although this is not so in most conifers. During this interval many changes occur in the female cone and ovule. The cone as a whole enlarges and turns green. The embryo-sac grows and forms inside a mass of tissue that corresponds to the *prothallus* of the fern. Female cells develop in this prothallus.

In the spring of the second year (i.e. nearly a year after pollination) the pollen-tube again begins to grow and reaches the female cells. Within the pollen tube the pollen cells have been dividing and eventually produce a male cell that joins with *one* of the female cells to produce an embryo. This is the act of *fertilization*. Repeated division of the embryo cells produces a tiny pine plant consisting of root, stem and some seed-leaves *(cotyledons)*. The prothallus becomes swollen with food tissue and the nucellus almost completely disappears. The covering of the ovule hardens and becomes the seed coat.

The changes associated with fertilization and seed development take about a year. The female cones, when ripe, are brown and woody. The scales open in dry weather and release the seeds which are provided with a thin membrane from the upper surface of the scale. Thus, in the Pine, the seeds are shed in the third year of the life of the cones, a little over two years after their first appearance. The majority of the conifers, however, require only one year for the process.

A branch of the Pine in spring. At the tops of the upper shoots are the young female cones. The female cones just below them were pollinated the previous year and now contain fertilized ovules. The brown mature cone is two years old and is now shedding its seeds. This year's male cones are on the lower shoots. (insets) (a) Section of a male cone showing pollen sacs and pollen grains. (b) Section of an ovuliferous scale and mature ovule. (c) A section of a young female cone showing the scales and ovules.

Linnaeus the classifier



As A naturalist Carl von Linné, or Linnaeus as he is better known, must rank second only to Charles Darwin.

During his life he wrote several Natural History books of great value, the most important of which was *Systema Naturae*. This included a classification of every animal and plant known at that time. Although his classification has been modified considerably he established the binomial system by which each plant and animal has two Latin names. The first is its generic name, and the second is its specific name. Thus man is called *Homo sapiens*. Each living thing therefore was given a slot in the filing cabinet of living things. He created some order for the previously unmanageable mass of known facts and it was made possible for biologists the world over to refer specifically to a particular organism. He might well be credited with establishing a means of communication in biology.

Linnaeus was born in 1707, the first son of a Swedish clergyman. As a child he spent many of his leisure hours collecting animals and plants.

He studied medicine, first at Uppsala University in Sweden and then in Holland, returning to practise in Sweden. The collection of detailed observations of specimens still remained a major interest, however, and from 1741, when he became a professor at Uppsala and received the botanical garden there, until the end of his life he devoted most of his time to this pursuit.

Though Linnaeus was primarily a classifier or systematist he made many observations outside this facet of Biology. Such were his experiments on the breeding of plants under varied conditions.

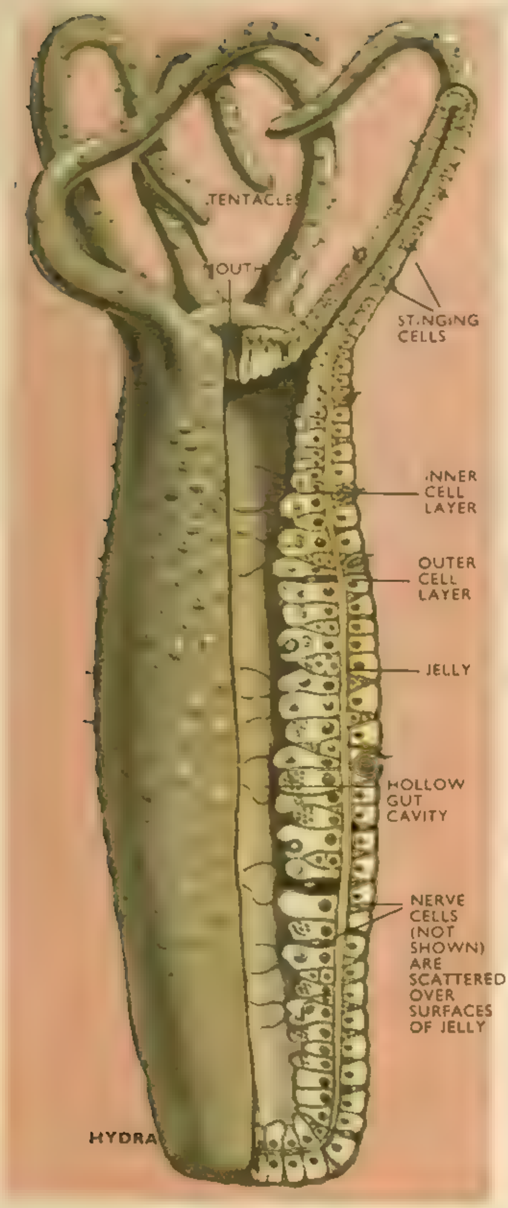
Linnaeus died in 1778. His fabulous collection of plants still exists and is on show at the rooms of the Linnean Society in London.

The flower heads of three plants that Linnaeus named.

3. Animal Physiology

Introducing the

Before an engine will work its parts must have been accurately made, and put together in the right way, and it must be supplied with such materials as fuel and lubricating oil; from time to time worn out parts must be replaced. If you want to know how an engine works you must find out how its parts are connected, what each part does, and what materials must be supplied to keep it going. Living things have working parts too; these parts must be 'put together in the right way and accurately made' in order that the animal or plant will live. Living things must

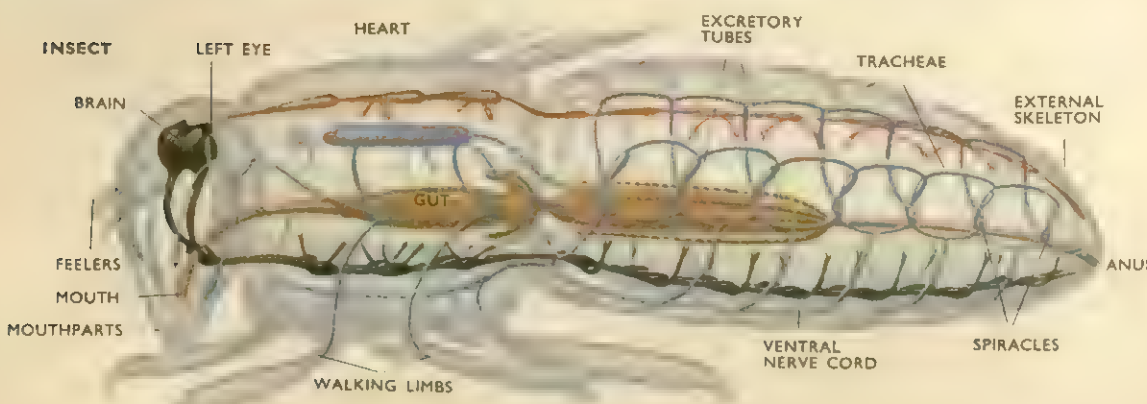


Hydra

In many simple animals the body consists of a hollow sac with an opening—the 'mouth'—at one end into which the food is pushed. The cells lining the sac surround the food and digest it. There are no special organs for breathing or getting rid of waste. Oxygen in solution 'seeps' in through the whole body surface and waste materials 'seep' out in the same way. *Hydra's* body wall is made up of two layers of cells in between which is a layer of jelly. Over the inner and outer surfaces of the jelly are scattered nerve cells from which branch nerve strands or fibres. Each cell remains separate, however, and nerve signals have to 'jump' the gaps in between. The inner ends of some cells in the outer layer of the body wall and of the tentacles are drawn out into muscle tails. *Hydra* has a soft, flexible body so that when these muscle tails shorten or lengthen the body can bend, stretch or even shorten into a round ball, the tentacles can move to catch food with special stinging cells and push it into the mouth, and the animal can move from one place to another by somersaulting.

Insects

Insects have a hard *outer* covering or *external* skeleton which contains a substance called chitin and hard protein. It covers the head, body and legs. The skeleton is light and jointed to allow the various parts of the body to move freely in relation to one another, worked by muscles which are attached to its *inside*. An insect's gut is a long, straight tube with an opening at each end. The majority of insects live on land. They breathe air in through a special system of finely branching tubes *(tracheae)* which open to the outside through holes along the sides of the body called *spiracles*. Air enters these and passes down the tubes to the finest branches which are in close contact with the tissues. It dissolves in fluid that



Living Processes

also be supplied with substances from outside – food, air, water. If you want to know how the body of an animal or plant works you must first 'take it to pieces' to find out what its working parts are, and what they do, and what they need in order to do it.

Animals feed, but where does the food go and what happens to it on the way? Animals breathe but what happens to the air when it is inside the animal; or to the water if the animal happens to be a fish? Animals excrete but where are the excretions made and from what? These are the kind of questions which it is the physiologist's task to answer.

fills the finer branches, passing the short distance to the tissues in solution. Insects have a well-developed nervous system with a brain at the head end from which a double strand of tissue, the nerve cord, passes back to the hind end of the body. In each segment of the body the nerve cord is enlarged as a local control centre.

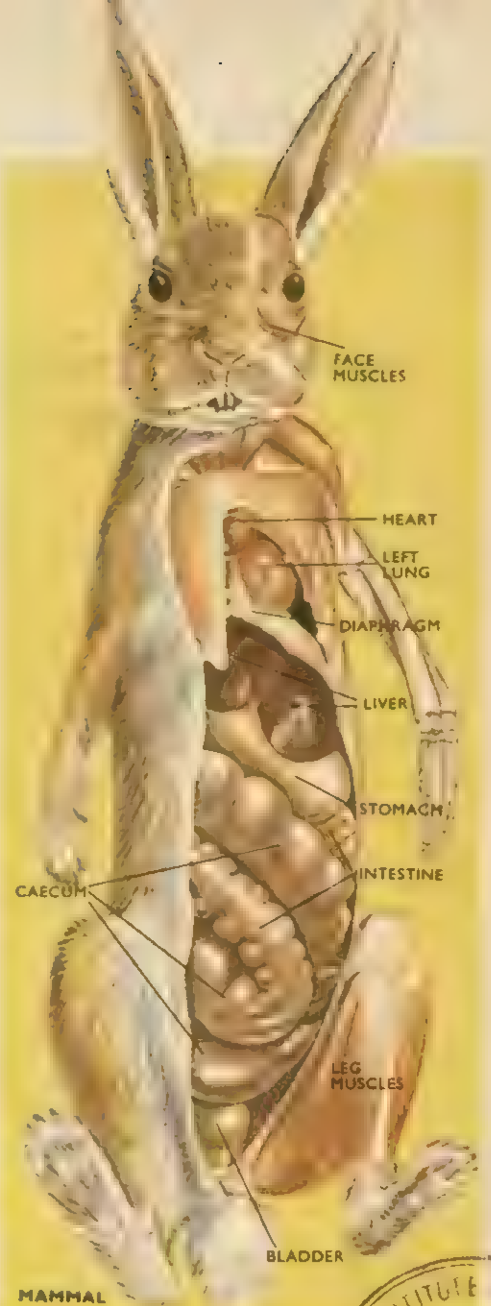
Fishes

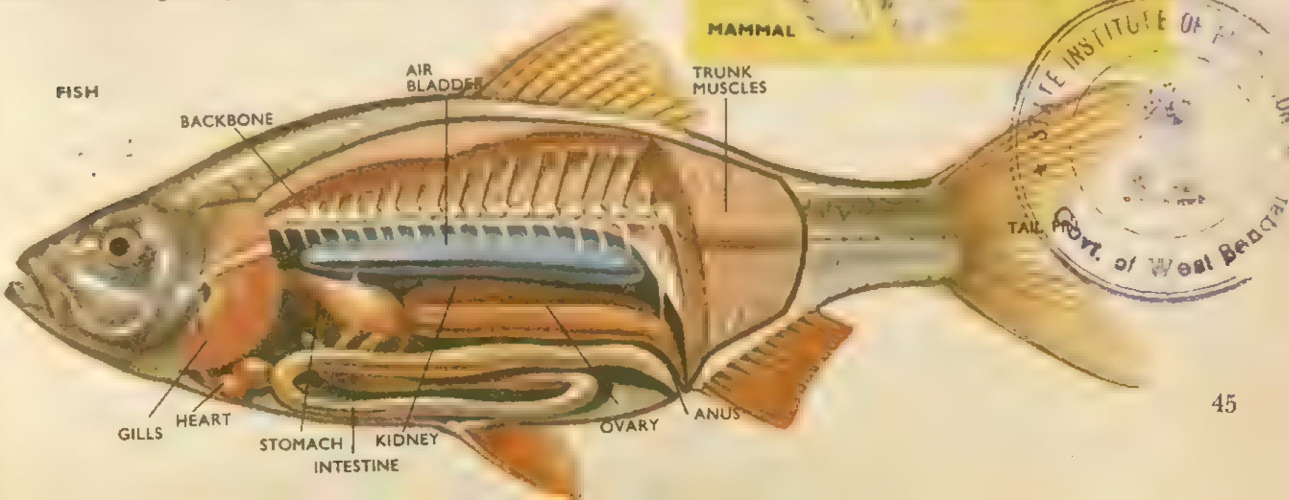
A fish is beautifully adapted for living in water. It has a bony *internal* skeleton. The bones move on one another at joints, and are worked by muscles attached to their outer surfaces. The bulk of the muscles are the ≷-shaped trunk muscles. They contract on alternate sides of the body from the front to the rear, bending the body in a moving wave that pushes against the water and forces the fish forwards. Fishes use their fins for braking, making sharp turns and varying their depth in the water. But they also possess an *air bladder* for maintaining their depth. This is a long, hollow sac inside the body cavity just above the gut. Parts of the bladder can release oxygen gas into its interior. This makes the fish buoyant and so it rises in the water. Other parts can remove oxygen gas, when necessary, making the fish less buoyant so that it sinks

The breathing organs *(gills)* take up oxygen that is dissolved in the water. It is carried round the body in the blood. The gut is a long tube with openings at both ends, and waste materials are removed by the kidneys. A fish has an outer protective covering of scales.

Mammals

Mammals have a bony *internal* skeleton. The bones and muscles of the legs carry the whole weight of the body while





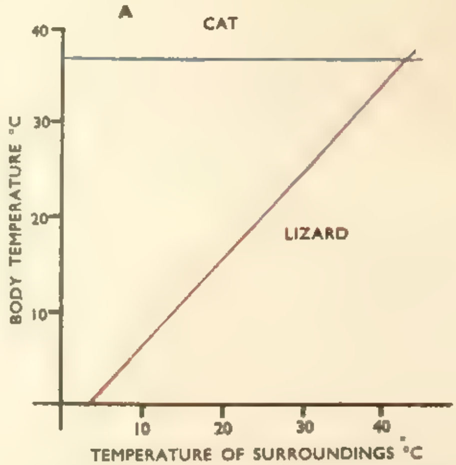
Man

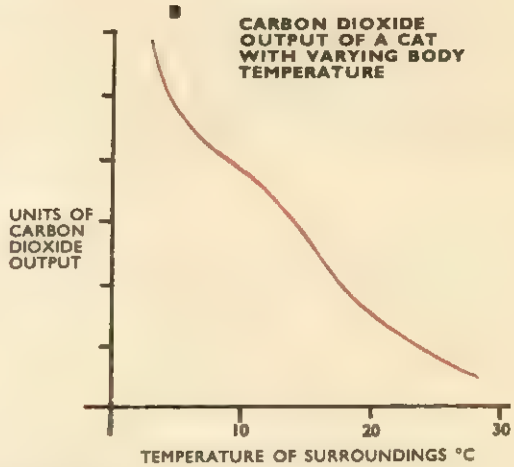
Man, like rabbits, horses, sheep, cats and dogs, is a mammal. Like other mammals he has a bony, *internal* skeleton; the organs in the lower part of his body *(abdomen)* are separated from the heart and lungs within the chest cavity by a sheet of muscle—the *diaphragm*; his gut is a long tube with an opening at each end and most of it is coiled within the abdomen; both the upper and lower jaws carry teeth; his head can be moved independently of his backbone. But Man has certain special characteristics. He is an animal that walks upright on two legs and uses his arms and hands for manipulation. The arms move freely in most directions, unlike animals which run on four legs whose arms move mainly in a fore and aft direction. He has a very large brain, by means of which he has devised methods of communication that allow each man to share the information of others, particularly by speech and writing. His eyes are large and forwardly directed. In the rabbit, where the small intestine leads to the large intestine, there is a large blind sac called the caecum at the end of which is the appendix. A rabbit eats plant material almost entirely and it is in the caecum that bacteria digest much of the plant food. In humans, which eat almost anything, the caecum is very small and the appendix is a short blind tube off it. Bacteria in the appendix may possibly play a minor part though the appendix can be removed without any apparent ill effects.

the backbone is a 'girder' between them from which the gut and other organs hang. The legs themselves are levers worked by the leg muscles and, by their movements, the animal is able to move from one place to another, often at great speed. In the rabbit, the hind legs are long and provide the drive for hopping. In large mammals, too, such as horses, the hind legs provide the drive for running while the front legs take the weight. As in birds, the rib cage protects the lungs and heart, but an important difference is the separation of these organs from the lower part of the body (abdomen) by a thin sheet of muscle—the *diaphragm.* This, with the ribs and their muscles, works to enlarge the chest, so drawing air into the lungs, and, to reduce its size again, so forcing air out. In most mammals the diaphragm moves backwards and forwards, but in humans it moves up and down because the body is upright. Mammals are *warm-blooded* and have a covering of *hair* which helps to reduce heat loss through the skin.

PROBLEMS

1.



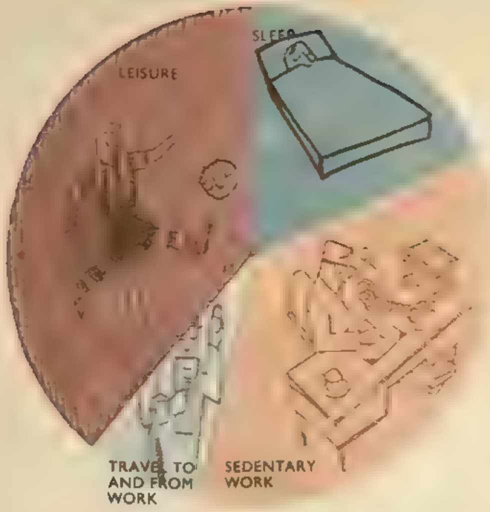


1. What does graph A tell you about the body temperature of these two animals?
2. Body activity depends on chemical changes which usually slow down at low temperatures
   a) Where would you *not* expect to find lizards on the Earth's surface?
   b) When would a lizard be easier to catch: 6 a.m. or 12 noon?
3. The amount of carbon dioxide an animal produces is a measure of the amount of energy it is releasing. What does graph B tell us about energy release and temperature control?

2.

Two animals were placed at different times in different dilutions of sea water and samples of their blood were analysed to measure dissolved substances

a) Why is a sea worm unable to live in fresh-water?
b) What can the crab do which the worm is unable to do?



The circle represents 3,000 Calories, the average daily intake of an adult.

Food and Feeding

IMAGINE a motor-bike that could supply itself with fuel, replace its own worn-out parts and, either on its own or in collaboration with another similar machine, make copies of itself. This is exactly what plants and animals can do. To do this they need energy and raw materials. These are supplied in *foods*.

The methods of feeding and the type of food eaten vary considerably. But between many of the widely different groups of animals there is often close similarity between the basic plans of the alimentary systems and between the juices (containing enzymes) that are released to break down or digest the food. For example, enzymes found in man have been isolated from simple one-celled animals.

Some animals *(herbivores)* obtain their nourishment by eating plants; others *(carnivores)* eat other animals, while many—called *omnivores*—eat both meat and vegetable matter. Yet others *(parasites)* live attached to other animals and feed off them.

Most plants are able to use simple molecules for food. Animals are not equipped to do this, so they (the *consumers*) rely upon the green plants (the *producers*) for their food. This is so whether they eat plant material or other animals, for at some stage in every food chain a plant is consumed.

The complicated food molecules that an animal eats have to be split into simpler ones before the animal is able to incorporate them in its own tissues. This is the purpose of digestion.

A Healthy Diet

In order to remain healthy an animal's diet must include the following substances: *proteins*, *fats*, *carbohydrates*, certain *minerals*, *water* and, in minute quantities, *vitamins*. Carbohydrates and fats are the main suppliers of energy, though proteins may also be 'burnt' to supply energy. Minerals are needed for such tasks as making bones and for the workings of nerves and muscles. Phosphorus is extremely important because phosphate-containing compounds store energy that may be released for such purposes as muscle contraction.

Foodstuffs

Life is based upon the unique ability of carbon atoms to join together in long chains and in rings with hydrogen and oxygen atoms and also with nitrogen, sulphur and phosphorus. Three main classes of carbon compounds are characteristic of plants and animals. They are *carbohydrates*, *fats*, and *proteins*.

Carbohydrates

Carbohydrates are compounds that contain carbon, hydrogen and oxygen. The latter two are usually present in the same ratio as in water, namely two hydrogen atoms to one oxygen atom. Examples are *glucose* (grape sugar), *sucrose* (cane sugar), *starch* and *cellulose* (a substance that forms the structural framework of plants). Except for water carbohydrates form the largest part by weight of the diet.

Fats

Fats contain only carbon, hydrogen and oxygen but the proportion of oxygen is less than in carbohydrates A greater proportion of fat is burnable material so that, of equal amounts of fat and carbohydrate, fat yields more than twice as much energy and also more water. Fats

Composition of various foods.

Place mats which are drawn to scale to show how the average daily intake of 3,000 Calories is made up in a typical diet. Note that the main meal which may be at midday or in the evening provides most of the Calories and also that 'elevenses' and afternoon tea can provide a considerable number of Calories, principally because of biscuits and sugar which are rich sources of carbohydrate.

A world map showing the intake of Calories per head per day in the seven main regions. Each saucer also shows the proportion of this total number of Calories contributed by carbohydrates. The small cubes alongside the plates represent the daily intake of protein per head per day.

Food Quality

How much carbohydrate, fat and protein do we need to eat each day and which foods can supply them adequately? We all know that 'starchy' foods such as bread and potatoes can cause us to grow fat. For this reason a slimming diet excludes such foods

The daily diet of the average adult must supply around 3,000 Calories (a Calorie = 1,000 calories – the amount of heat energy required to raise the temperature of 1 *litre* of water 1 *degree* Centigrade). The figure varies enormously depending on age, sex, occupation, activity and state of health. A lumberjack obviously expends more energy at work than a clerk, and conditions of illness or pregnancy will make special demands. If sufficient calories are not supplied in the diet a person will lose weight as the body's reserves are used up to supply the necessary energy

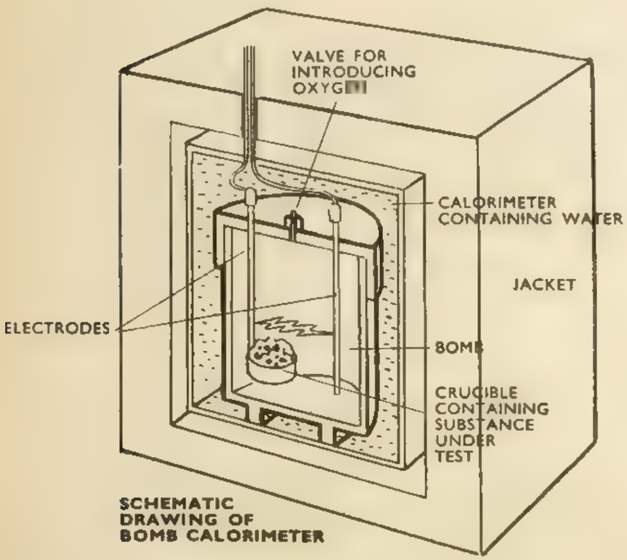
Carbohydrates are the main sources of energy. (1 gram of carbohydrate if completely 'burnt' supplies 4·1 Calories in the body.) Foods rich in them include cereals, bread and chocolate. Fat-rich foods include butter, margarine, cheese and pork. (1 gram of fat supplies 9·3 Calories). Rich sources of protein are eggs, fish, meat and peanuts. (1 gram of protein supplies 4·1 Calories.) Milk contains valuable amounts of all three main foods plus most vitamins and mineral salts containing calcium and phosphorus.

are important, economical storage materials for these reasons, especially to animals that inhabit dry desert regions.

Proteins

Protein molecules always contain nitrogen in addition to carbon, hydrogen and oxygen and sometimes sulphur and phosphorus too. Haemoglobin, the red colouring matter of blood, contains a protein. Together with water, proteins form the basis of all living matter or *protoplasm*. They also form part of the hereditary material that is carried on the chromosomes in all cell nuclei. Enzymes are also proteins. Proteins are also important structurally. Muscle is largely protein, for example. Many plant seeds contain protein stores. Proteins are used to supply a little energy in the body but they are less important in this respect than carbohydrates and fats.

Food substances contain energy. This can be measured in Calories using a bomb calorimeter in which food can be burnt electrically and the energy liberated is used to heat water in a surrounding jacket. The rise in temperature is a measure of the energy in the food.



Food testing—identifying the substances in food

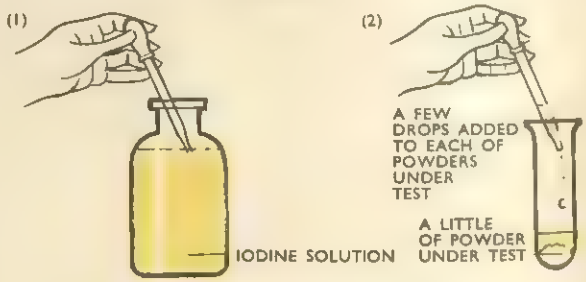
There are many ways of identifying substances, by their colour, melting points, freezing points, density, smell, taste, and so on. Some ways are obviously better than others because they are more convenient to use, or because they apply to one substance rather than a group of substances. Sometimes chemical tests in which one substance called a reagent is added to the substance under test help to show up a property of the substance which is not otherwise obvious. If this property is peculiar to the substance under test we can by such a chemical test pick it out from other similar substances.

Practical Problem

Test five whitish powders, casein (milk protein), starch, glucose, fibrin (blood protein), and powdered suet as follows:

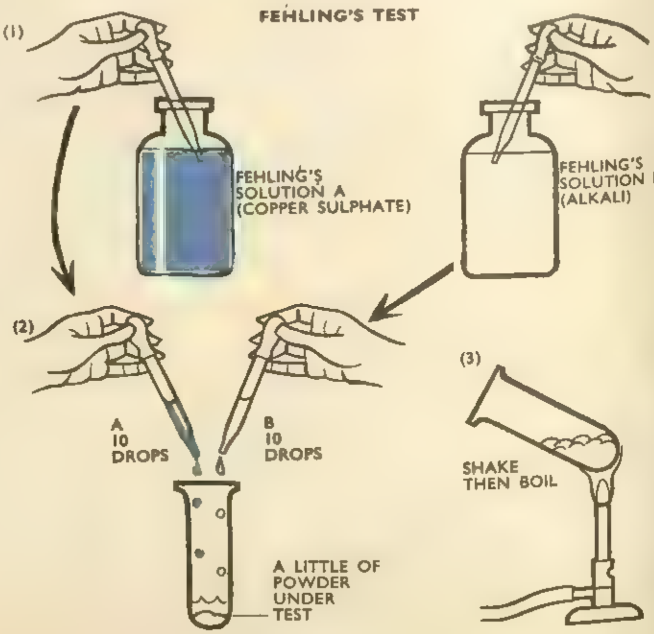
Test 1. Place a little powder in a boiling tube. Add a few drops of iodine solution to each in turn. Observe and report the results.

IODINE TEST

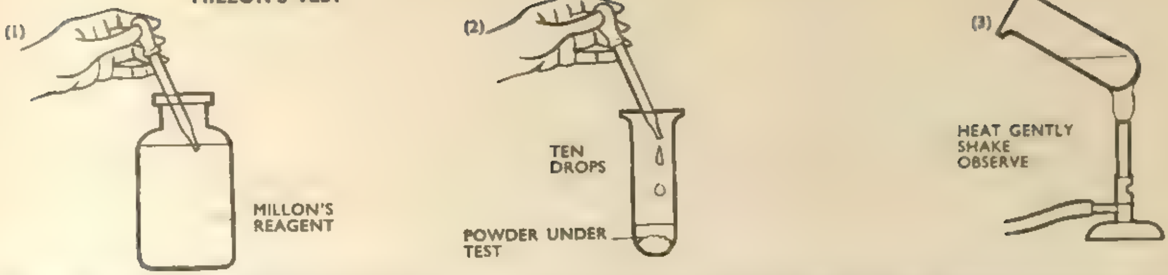


Test 2. Add to a little of each powder in a boiling tube ten drops of Fehling's A solution (copper sulphate solution) and then ten drops of Fehling's B solution (alkali) and boil. Observe and report the results.

FEHLING'S TEST



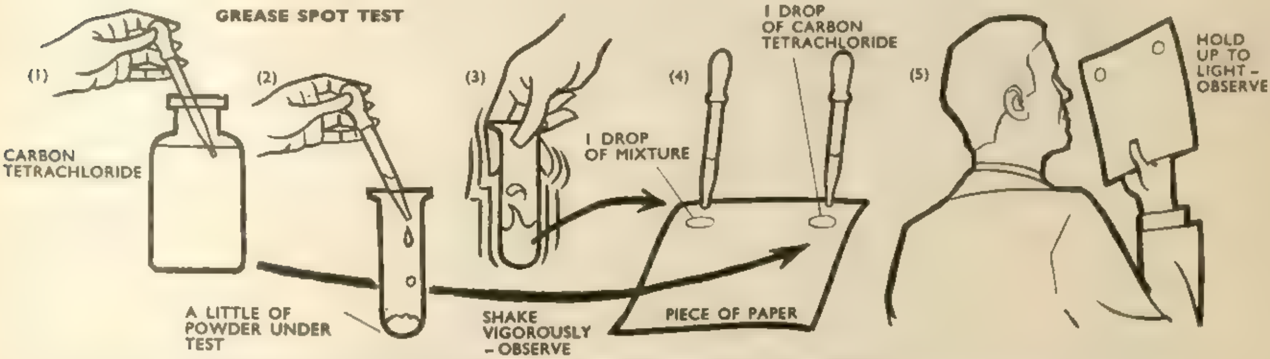
MILLON'S TEST



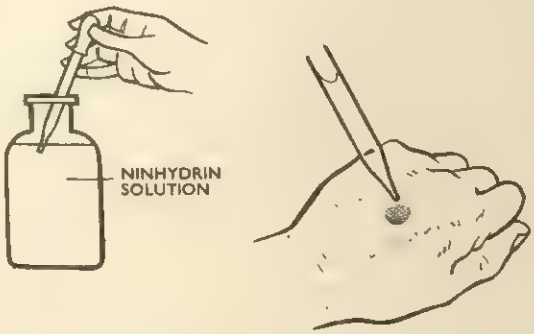
Test 3. Add to each powder, as above, a little Millon's reagent (taking care not to spill the reagent on your skin) and heat gently. Observe and report results.

Test 4. Find out if the powders will dissolve in carbon tetrachloride. Place a drop of solution on a piece of filter paper. Hold the paper up to light and observe. Repeat with carbon tetrachloride on its own and compare the results.

GREASE SPOT TEST

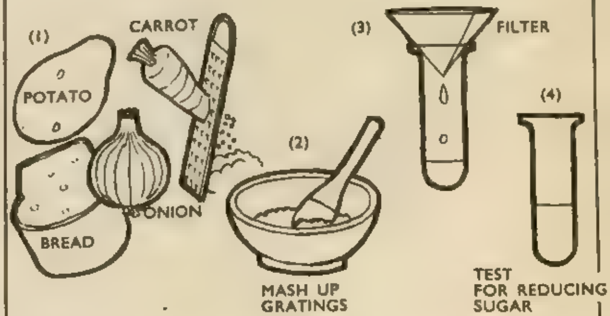


a Produce a table to summarise all the information you have obtained from these tests.
b. If you had been given a mixture of substances, say from a sample of school dinner, and this had given a black colour with iodine solution, what would this tell you?
c. If a powder had given a reddish colour with Millon's reagent, what colour would you have expected it to go with Fehling's?
d. Why was it necessary to repeat test number 4 with carbon tetrachloride alone?
e. As far as you can tell from the tests you have carried out, how does this information help you to identify substances in food?



PROBLEM

1. With a pipette place a drop of ninhydrin solution on the skin. What does the result indicate? (hint—see experiment on page 58).



PROBLEM

2. Crush grated carrot, onion, potato and bread in water and filter off the extracts. Test filtrate for reducing and non-reducing sugars with Fehling's or Benedict's solution.

MAIN VITAMINS NEEDED BY MAN

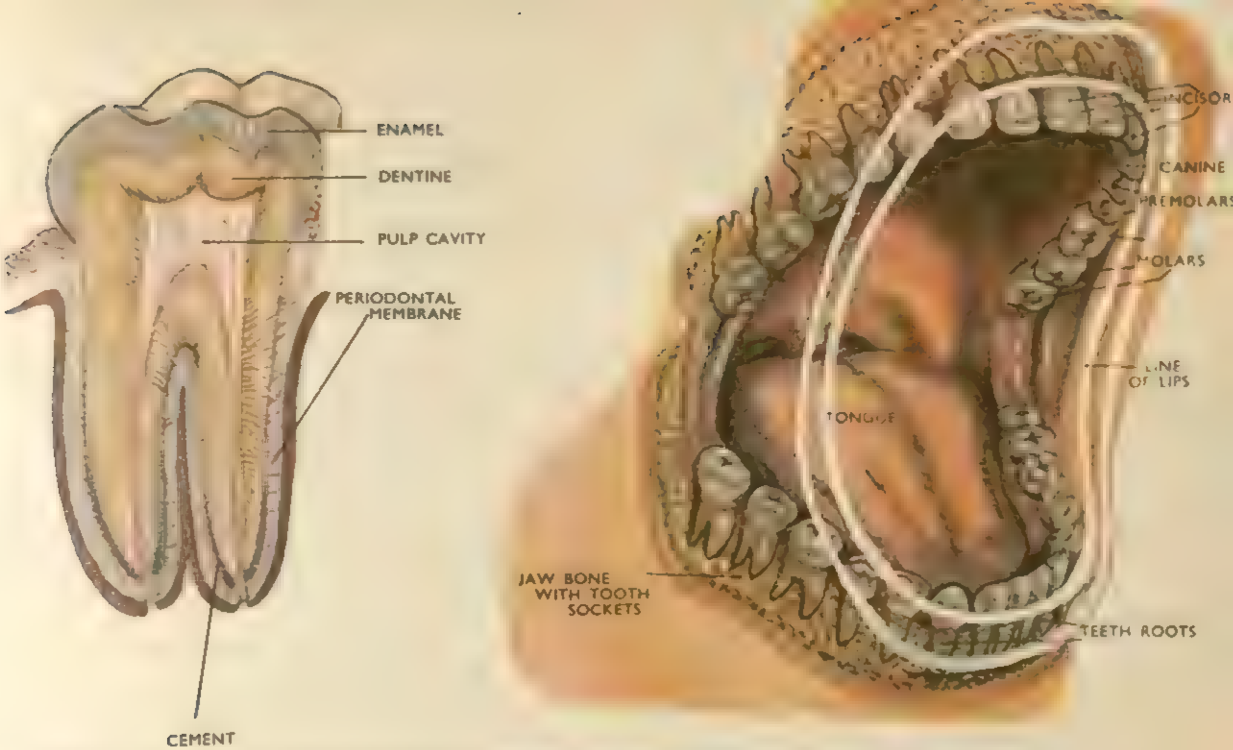
	VITAMIN	FOOD SOURCES	FUNCTION IN THE BODY	MAIN EFFECTS OF DEFICIENCY
FAT SOLUBLE	A (Axerophthol)	Fish liver oils, butter, eggs, margarine, cream, green vegetables, carrots.	Growth and building of new cells. Associated with resistance of epithelia to infection (particularly of eyes, gut and lung passages). Formation of eye pigments.	Xerophthalmia (hardening of cornea); Night blindness (poor vision in the dark); Dryness of skin; Poor bone growth.
	D_2 (Ergocalciferol)	Fish liver oils, margarine	Necessary for normal absorption of calcium and phosphorus.	Rickets; Osteomalacia (softening of the bones); Unhealthy teeth
	D_3 (Cholecalciferol)	Fish liver oils, butter, eggs, cream, liver, margarine.	Necessary for normal absorption of calcium and phosphorus.	Rickets; Osteomalacia (softening of the bones); Unhealthy teeth.
	E (Tocopherols)	Wheat germ oil, green vegetables, eggs	Necessary for proper development of foetuses and male sex cells. Prevents fats from being oxidized.	Inadequate nourishment of the muscles (muscular dystrophy). Loss of fertility.
	K_1 (Phylloquinone)	Lettuce, kale, spinach, pig liver, tomatoes.	Blood clotting process.	Loss of blood clotting power. Excessive bleeding (particularly in new born)
WATER SOLUBLE	B_1 (Thiamine)	Yeast, whole cereals, liver, eggs.	Important in carbohydrate metabolism.	Beri-Beri.
	B_2 (Riboflavin)	Milk, yeast, liver, wheat germ, green vegetables.	Vital part in cell chemistry, particularly oxidations.	Inflammation of the tongue
	B_3 (Nicotinic acid)	Liver, kidney, meat, wheat germ, yeast, green vegetables.	Part of some enzyme systems; important in carbohydrate and protein metabolism.	Dermatitis (inflammation of the skin). Pellagra (disease affecting alimentary system, skin and nervous system)
	H (Biotin)	Liver, kidney, egg yolk, milk, vegetables, nuts.	Necessary for the action of some enzymes (e.g. those causing breakdown of unwanted proteins).	Dermatitis, Muscle pains; Loss of appetite.
	B_{12} (Cyanocobalamin)	Liver.	Necessary for formation of red blood cells, synthesis of methyl (CH_3) groups.	Pernicious anaemia (blood disease). Spinal cord wastes away.
	C (Ascorbic acid)	Oranges, lemons, grapefruit, tomatoes, uncooked vegetables.	Formation of collagen. Healing of injuries.	Scurvy (bleeding of gums and other parts of body, painful joints).
	Choline	Liver, pancreas, soya beans.	Fat metabolism. Synthesis of acetylcholine (substance released at nerve endings). Exchange of methyl groups between substances.	Cirrhosis (disease of the liver); Bleeding of kidney.

Many other vitamins have been discovered and are known to be necessary to other animals In man, folic acid plays a part in blood formation

Vitamins

Besides proteins, fats, carbohydrates, mineral salts and water, a healthy diet must include minute traces of *vitamins*. These are organic compounds whose absence or deficiency from the diet disrupts the normal workings of the body resulting in so-called *deficiency diseases*. Vitamins have been discovered as a result of investigations into these diseases.

The first scientific investigation into deficiency diseases was probably carried out by Christian Eijkman, a Dutchman, working in Java, who fed fowls on polished rice (rice from which the husks have been removed). They developed similar symptoms to some of the Javanese who suffered from a mysterious ailment. When they were fed on unmilled rice the poultry recovered. Eijkman and other workers then realised that the disease was caused not by a germ but that it was due to the absence of some substance from the diet. This substance must be present in the husk of the rice. Other experimenters, notably Sir Frederick Gowland Hopkins, discovered in keeping laboratory animals on an artificial diet that traces of natural foods, such as yeast and milk, must be added to their diet for them to remain healthy. Hopkins suggested that these natural foods contain minute quantities of substances that are vital for a balanced diet. He called them *accessory food factors* and they later became known as vitamins.



Mouth and jaws of adult human showing the position of the teeth. Left, vertical section of a molar tooth.

The structure and development of human teeth

An adult human being normally has thirty-two teeth, sixteen in each jaw. The upper jaw has on each side two *incisors*, one *canine*, two *premolars* and, at the back, three *molars*. The same is true of the lower jaw. The number of teeth in an animal can be expressed quite conveniently by using the dental formula. This gives the number of teeth of each type in one half of each jaw reading from front *(incisors)* to back *(molars)*. Thus the dental formula for man is $\frac{2123}{2123}$. For a rabbit, which has no canine teeth at all in its jaws, the formula is $\frac{2033}{1023}$. The tooth arrangement depends to a large extent upon the feeding method and the nature of the food. Man is an omnivorous animal (he eats all types of food) and consequently our teeth are not highly specialised when we compare them with the grinding teeth of herbivores and the cutting teeth of carnivorous animals. Incisors are retained in most mammalian groups as chisel-shaped biting or cutting teeth. The canine is highly developed in hunting carnivores (e.g. cats) as a stabbing and tearing tooth. In man it is rather reduced and functions almost as another incisor. Many herbivorous animals have lost the canine teeth altogether in the upper jaw. The premolars and molars of man are the grinding and chewing teeth. The surface of these teeth is covered with triangular or conical ridges *(cusps)* which fit into the hollows of the opposing teeth when the jaws are brought together. Chewing movements then cause the teeth to act as millstones and grind up the food.

Although our teeth are modified for various purposes they are all constructed according to a definite pattern. Projecting from the gum is the *crown* of the tooth. The part embedded in the gum and reaching into a socket in the jaw bone is known as the *root*. The body of the tooth is made up of a hard, bone-like substance called *dentine*. Inside this there is a cavity—the *pulp cavity*—which contains blood vessels and nerves. Branches from these, together with fine protoplasmic threads, penetrate the maze of fine canals which spread throughout the dentine. When the latter is damaged by decay, or by the dentist's drill, the nerve endings are stimulated and we feel pain. Covering the crown of the tooth is a layer of *enamel* of varying thickness. Around the root of the tooth, enamel is replaced by *cementum* (the cement), another bone-like material which fixes the tooth firmly in the socket of the jaw. Incisor and canine teeth have a double root and molars have three branches to the root.

We have seen that an adult has thirty-two teeth but a young child up to the age of about six has only twenty teeth. These are the *milk* teeth which are gradually replaced by the permanent teeth after the age of about six years. There are no molars in the

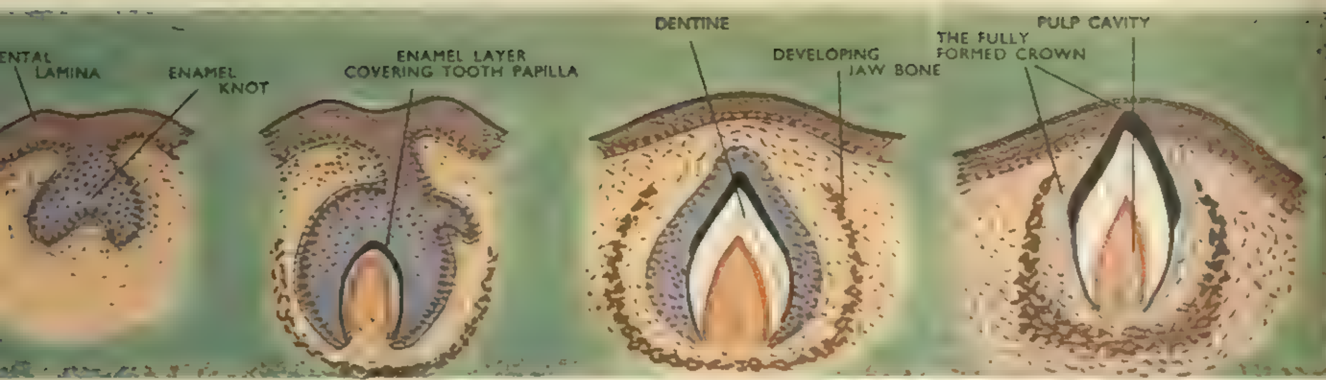
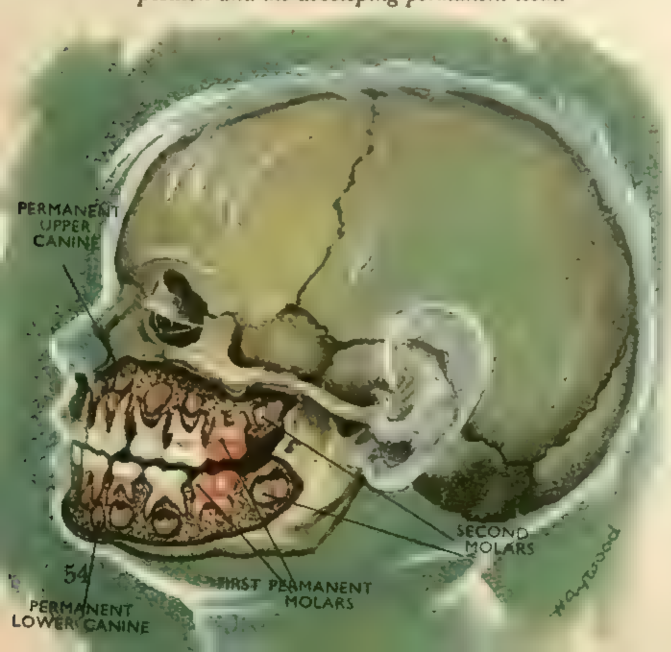


Diagram of six stages in the development of an incisor from the bud to the fully developed tooth.

milk set. The first milk teeth to erupt are the incisors which normally appear between eight and ten months after birth. The full set does not normally appear until two years of age. The first *permanent* teeth appear at the age of about six years. They are the front molars. The milk teeth are then replaced by the permanent ones which grow up under them. Incisors are replaced first, then premolars, and then canines, the latter appearing as permanent teeth at eleven years or so. The second molars appear at about 12 years and the third molars—wisdom teeth—not until eighteen or even later.

Although the teeth are composed of a hard bone-like tissue, they are in fact derived from various skin tissues in much the same way as shark scales. Just like teeth, shark scales have a pulp cavity surrounded by dentine and enamel, and, in only slightly modified form, function as teeth in the mouths of sharks.

The head of a six-year-old child showing the milk teeth in position and the developing permanent teeth.



Human teeth are formed in the following way. In the early embryo the skin along the future line of the jaw-bones thickens and is known as the *dental lamina*. The edge of this extends into the tissues of the jaw and forms bud-like thickenings at intervals along the jaw. There are, at first, ten of these thickenings. They are the buds of the first set of teeth.

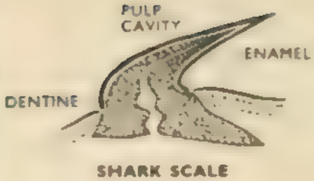
The dental lamina later extends beyond the last milk tooth bud and slowly forms the buds of the permanent molars. Six months before the baby is born the lamina forms further tooth buds on the inside of the developing milk teeth. These are the buds of the permanent teeth. They develop in just the same way as the milk teeth but much more slowly.

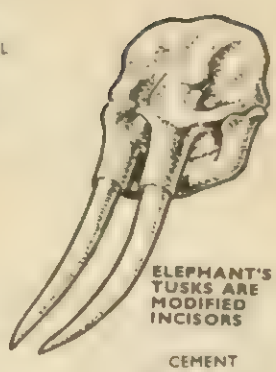
The surface tissues of the tooth buds grow inwards and form a bell-shaped structure in which a group of cells shows up densely and is termed the *enamel knot*. Under this knot, cells of connective tissue become dense, forming the beginnings of the tooth body, the tooth *papilla*.

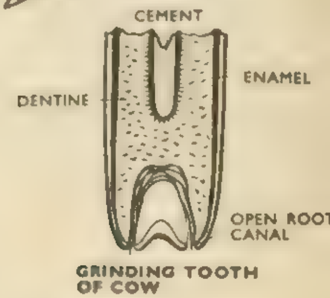
In other mammals and in some of the less civilised races of man the permanent teeth remain healthy throughout life but, particularly in western civilisation, dental disease is on the increase and frequently necessitates removal of these teeth and their replacement with artificial ones.

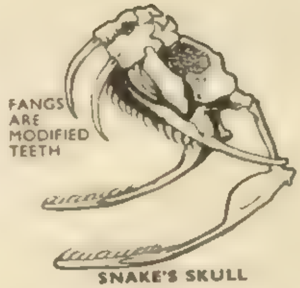
Teeth in other vertebrates

Only in the mammals do we find the various types of tooth described here. In all lower vertebrates the teeth are simple conical structures, usually without roots, and are present in greater numbers than in mammals as a rule. They are attached to the jaws by cement or by fibrous tissue (ligaments) but, apart from crocodile and some fish teeth, they are not









placed in sockets. Frequently, especially in fish, teeth are found in the roof and base of the mouth as well as in the jaws. Although the size of teeth may vary in an individual animal—the crocodiles have both large and small teeth—all are of the same general shape. Some modifications are found in fishes which feed on molluscs. The teeth are often flattened and may be joined together in plates in order to crush the shells. The poison fangs of snakes are modified teeth. They are elongated and grooved to carry the venom from the poison glands into the wound made by the teeth. In contrast with mammals, where there are usually the two sets of teeth described for man, reptiles and most other lower vertebrates replace their teeth many times, new ones replacing worn ones regularly throughout life.

Modern birds are without teeth, although fossils show that the earliest birds had simple conical teeth similar to those of their reptilian ancestors.

All mammalian teeth can be classed by the four types described at the beginning of the article but, as we have seen, they may be modified according to the feeding habits and diet of the animals concerned. The molars of cows and other grass- or foliage-feeding animals are very large and have a complex pattern of ridges and grooves to ensure adequate grinding of food. Teeth such as these, which are subjected to hard wear, continue to grow throughout life as the root canal remains open. The dog and related carnivores have very sharp, pointed *carnassial* teeth. These are formed by the last pair of premolars of the upper jaw. The chewing motion of the jaws causes the teeth to shear through the meat. Other tooth modifications include the tusks of elephants—greatly enlarged upper incisors. Whalebone whales and some ant-eating mammals have no teeth at all.

PROBLEMS

1. Describe the dental formula of this animal
2. What is the diet of the animal?
3. What is attached to (A)?
4. What is the shape and job of (B)?

1. Describe the dental formula of this animal.
2. What is the diet of the animal?

Under two headings. 1. Shape of jaw and relative size of parts. 2. Teeth. List as many differences as you can between the two skulls.

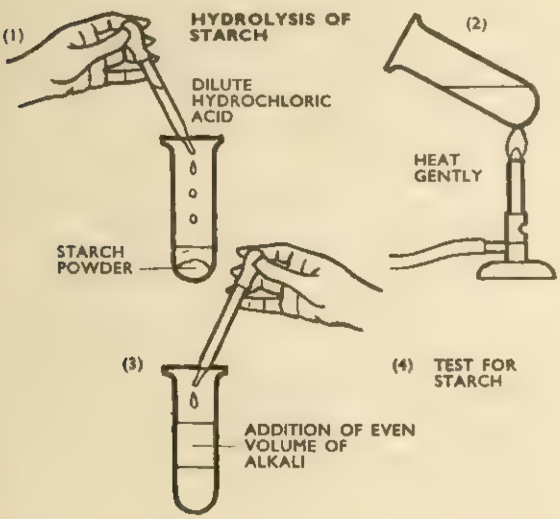
Hydrolysis—a practical introduction

Starch is plentiful in the diet of humans. Starch is not soluble in cold water or water at body temperature. Insoluble substances, with the possible exception of fats, cannot get out of the alimentary canal into the blood stream.

How could the question be answered? Does the starch pass through the alimentary canal unchanged?

If starch is used by the body, what must happen to the starch on its way through the alimentary canal?

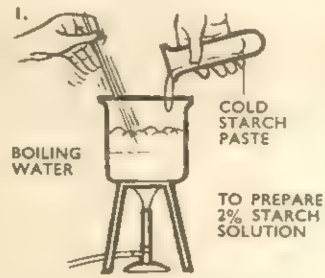
A. How can insoluble substances be made soluble? Chalk is insoluble in water but if we add dilute hydrochloric acid to the water, what happens? Do the experiment and find out the following.
Where has the chalk gone? What is the other substance formed? Where did this come from? What kind of change has taken place?
Add dilute hydrochloric acid to some starch powder in a boiling tube. Now heat gently to boiling point. What happens? Neutralize with approximately the same volume of the same strength alkali and by the test which you know, test for starch. Before testing find out if the neutralized mixture contains a substance insoluble in cold water.
What has happened to the starch?



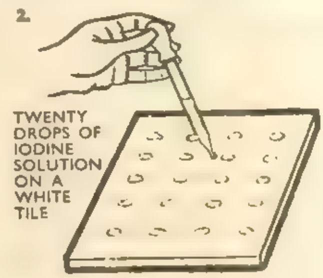
B What is the substance formed?
We know from the previous experiments that starch is changed into a soluble substance, but what is the substance likely to be?
Chemists can help us out here. They have discovered that starch contains the elements carbon, hydrogen and oxygen and that the proportions of these three elements are about the same in starch as in sugars. It is possible that a sugar or sugars might be formed when hot hydrochloric acid acts on starch. Try to design an experiment to find out.

C. The action of saliva on starch.
The first digestive juice with which starch in the food comes into contact is saliva. This investigation is to find out if saliva alters starch.
The method of investigation is very simple. Starch and saliva are mixed and samples of the mixture are tested from time to time with iodine solution.

a. First make up a starch 'solution' (this is not a proper solution) by adding a little starch paste made with cold water into boiling water, and allowing it to cool

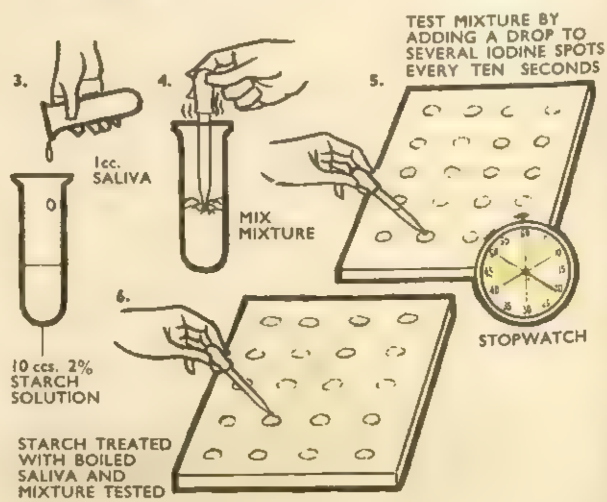


b. Now place about twenty spots of iodine solution on a white tile.



c. Add about 1 cc of 'neat' saliva to about 10 ccs of 2% starch 'solution'.

d. For mixing and taking samples a drawn tube with a rubber teat on the end is very useful.
Mix thoroughly and quickly. Take samples at about 10-second intervals and add to the iodine spots. Note the colours given.



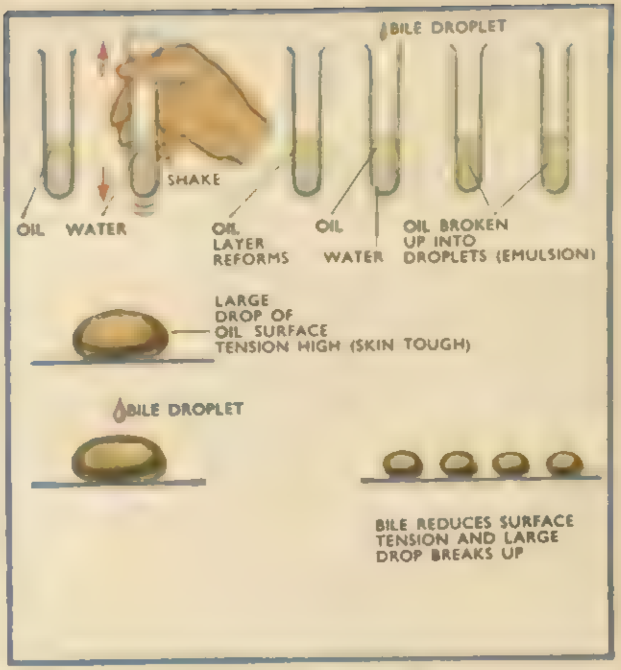
What do you conclude?
Does saliva contain hydrochloric acid?
Design an experiment to find out if sugar is produced in this case.
Why in such an experiment will it be necessary to test the saliva for sugar?
(On one occasion when the consultant to this book was doing this experiment with a class it was found that all the boys on the back bench gave a positive Fehling's test when their saliva was tested. No one else in the class obtained this result. Can you account for this phenomenon?)

D. The effect of boiling on saliva. Repeat the above experiment using well-boiled saliva. What is the effect on its action of boiling the saliva?

E. A substance which causes a chemical reaction to take place at lower temperatures, or lower pressures, or in less extreme conditions of acidity than it would if it were not present, is called a *catalyst*.

It is characteristic of catalysts that very small amounts are required to promote a chemical change even though the change they produce is large. Moreover they can be recovered at the end of the reaction.

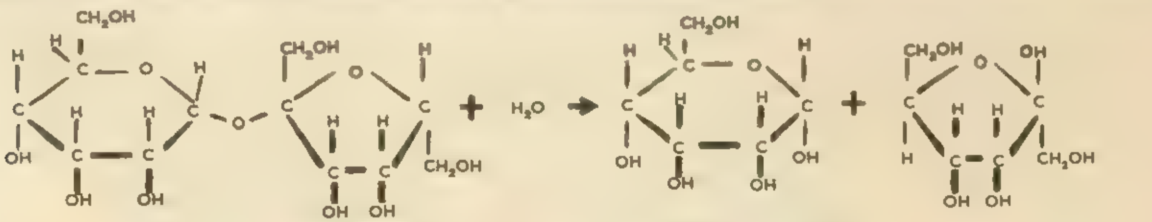
Catalysts from living things are called ENZYMES. What reasons can you give for thinking that there is a catalyst in saliva?



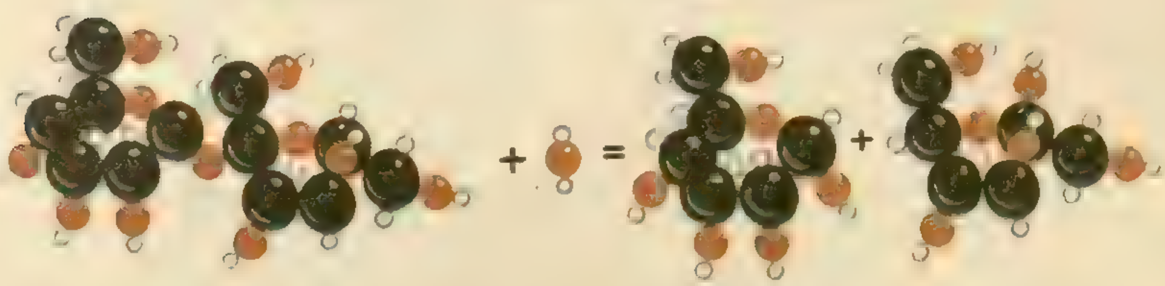
A grain of starch placed on the tongue has little taste, at first, but in a short time the enzyme in the saliva breaks the starch down into malt sugar (maltose) which is sweet to the taste. The starch has been *hydrolysed* to maltose. Hydrolysis means 'water-splitting'. In the presence of water in the saliva, starch is broken down into maltose. Water (H_2O) is split into a hydrogen (H) part and a hydroxyl (OH) part—and these tag on to the broken-up pieces of the starch molecules forming molecules of maltose. The essence of hydrolysis is that water itself is split—so is the compound with which water reacts. Another example of hydrolysis is the breakdown of cane sugar into glucose and fructose.

Hydrolysis is very important to living processes, particularly to digestion. All the enzymes that help to digest the foods in the gut, by breaking down the larger molecules into smaller ones, do so by the chemical process of hydrolysis. Many of the processes taking place inside animal and plant cells are also hydrolyses.

An equation summarising the hydrolysis of cane sugar (sucrose). Sucrose is split into glucose and fructose, the water molecule being split into 'H' and 'OH' parts, one of which is 'added to' glucose and the other to fructose.

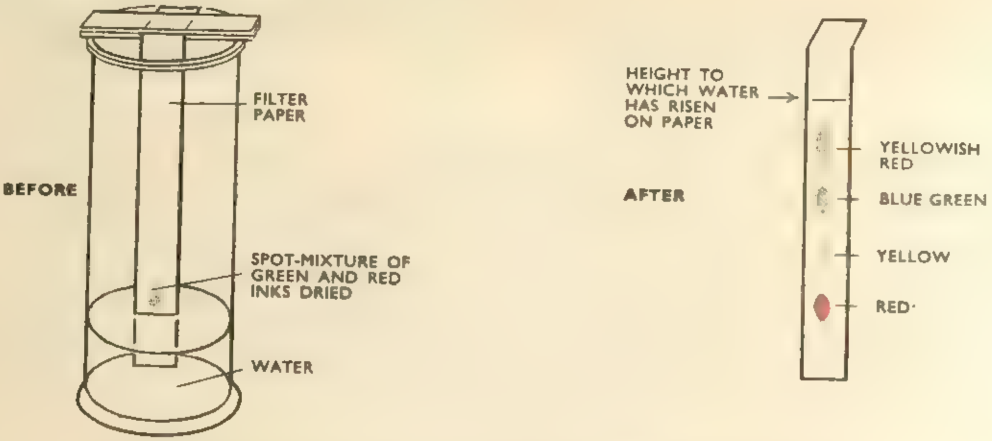


$C_{12}H_{22}O_{11}$ + H_2O = $C_6H_{12}O_6$ + $C_6H_{12}O_6$
SUCROSE (CANE SUGAR) WATER GLUCOSE FRUCTOSE



Hydrolysis—an investigation by means of chromatography

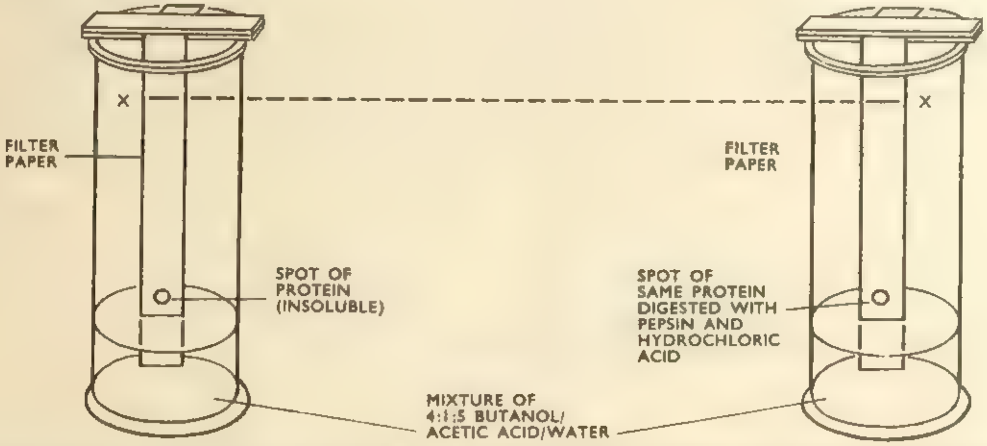
Study the following experiments and then answer the questions.



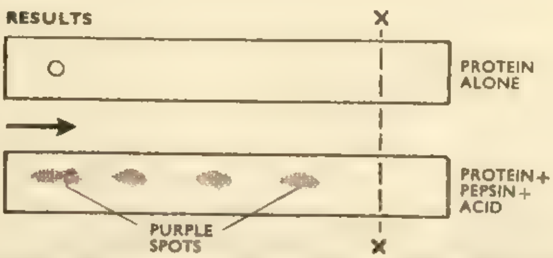
1. As the water "climbed" up the paper what has happened to the mixture?
2. Are the spots in the right order? Do the experiment and find out.

Hydrolysis of protein

HYDROLYSIS OF PROTEIN



Both papers are dried when the mixture reaches x – x and sprayed with a substance (ninhydrin) which gives a mauve coloration with proteins, peptones and amino acids.



What does this result suggest? Could the spots be caused by the pepsin by itself? How could you check on this?

Digestion

In humans the breakdown of the food begins in the mouth where it is mixed with saliva. This watery fluid contains an enzyme *ptyalin* that acts on starch and converts it to a sugar, maltose. The tongue and the teeth help to break the large food particles down to smaller ones and thus ensure that as much of the food as possible is exposed to the action of the ptyalin.

After the food has been mixed, partly digested and thoroughly wetted by the saliva, it is swallowed and passes down the *oesophagus* to the *stomach*. The food is moved through the *oesophagus* and the rest of the gut by the rhythmical contraction of the muscle in its wall. This muscle action is called *peristalsis*.

The stomach is a muscular bag that leads into a long, narrow tube, the *small intestine*. Where this joins the *large intestine* there is a short blind tube—the *caecum*—at the end of which is the *appendix*. The large intestine leads into the *rectum* which opens to the outside by way of the *anus*.

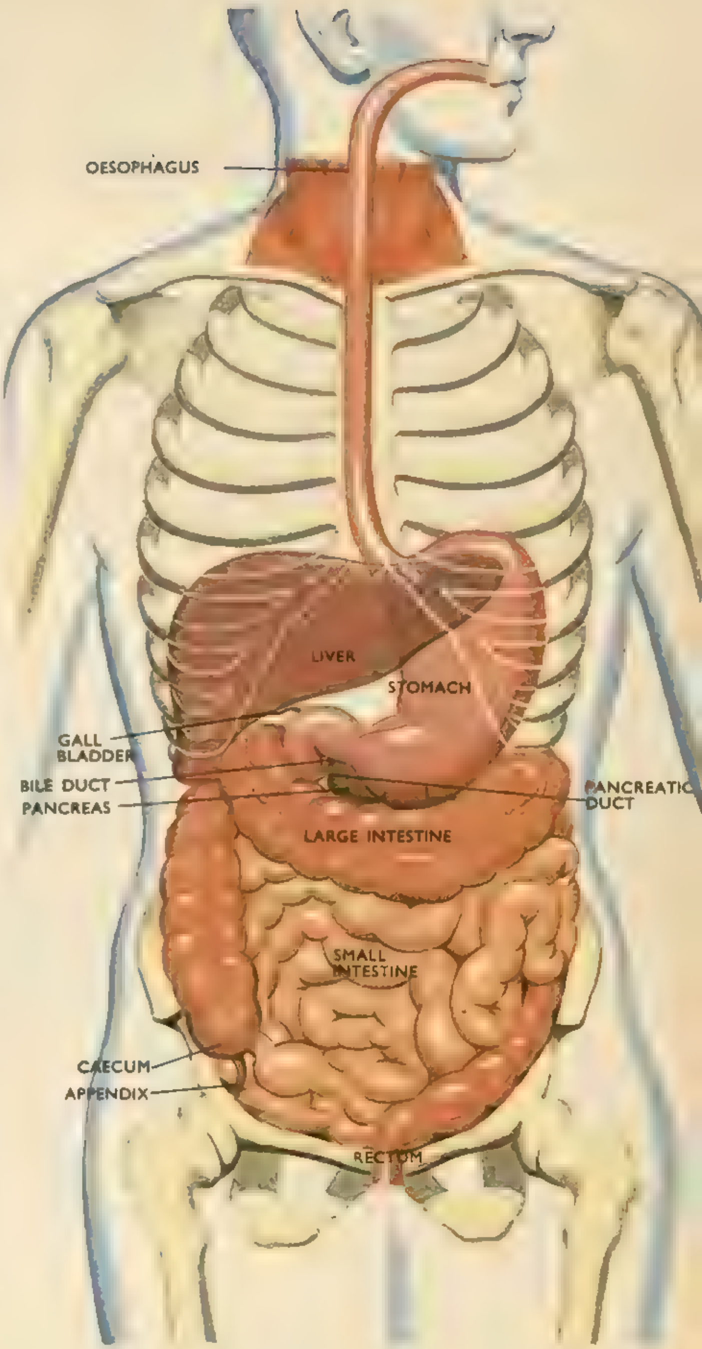
In the stomach the food is sterilized by *hydrochloric acid* produced by cells in the stomach lining. Other cells release an enzyme *pepsin* which starts the breakdown of proteins. Another enzyme, *rennin*, clots milk by acting on the protein in it. The passage of milk through the gut is slowed down so more of the food value is extracted. This is of great importance to young mammals where at first the sole food is milk from the mother. Together with *mucus* (slime) the food is mixed in the stomach to form a paste called *chyme*.

A ring muscle regulates the passage of food out of the stomach into the small intestine. The food has changed little chemically so far and only a small quantity has been absorbed by the stomach lining. In the small intestine many more enzymes are released and the chemical breakdown of the food is completed (see illustration page 60).

Absorption

Most of the absorption of food takes place in the small intestine. The large intestine is mainly concerned with the absorption of water. The passage of the food through the gut is eased by the production of mucus (slime). This also aids the formation of the *faeces* which consists of undigested food and, amongst other things, substances from the bile. The large intestine has no villi, but its wall has a rich supply of blood vessels that collect the water absorbed.

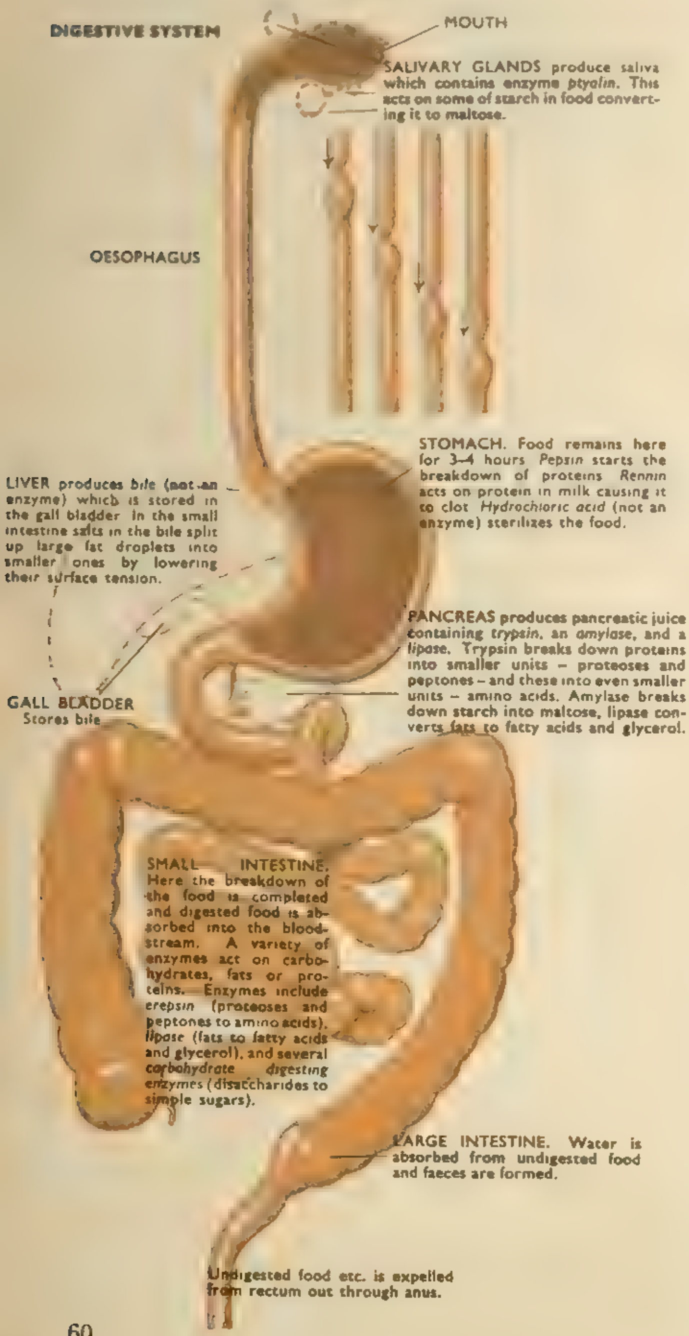
Amino acids and sugars are absorbed by the cells of the villi and pass from them into the blood capillaries there. These join to form the *hepatic portal*

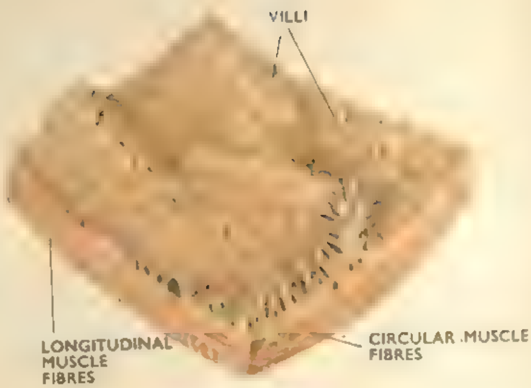


The human digestive system.

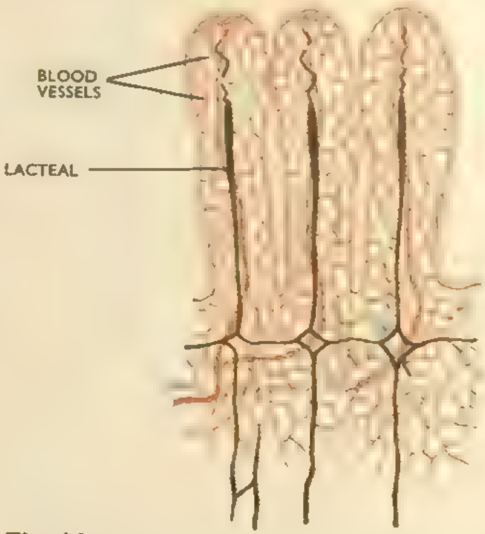
vein that carries them to the liver. Most of the fatty acids absorbed pass into spaces (lymph spaces) in the wall of the gut where they are built up into fats once more. Fat-collecting vessels called *lacteals* carry the fat to a main blood vessel entering the heart and it is distributed to the parts of the body that need it for fuel, or it is stored.

A summary of the changes that occur inside the alimentary canal.





A diagram showing the structure of the intestine. Note the large number of finger-like projections (villi) *which increase the surface area through which digested food can be absorbed, and also the two layers of muscle, circular and longitudinal, which work to propel the food through the intestine. (lower) A section through three villi showing the rich blood supply and also the fat-collecting vessels or* lacteals.



The Liver

The liver is the largest gland in the body. Its main task is the management of foodstuffs—fat, carbohydrate and protein—storing and/or converting them into the substances required by the tissues; sugar to provide energy, proteins for building and repair work, fat as fuel or storage material. Amino acids (the constituents of proteins) in excess of the body's requirements cannot be stored. The liver cells break them up and eventually convert them into carbohydrates—which can be stored or oxidized to provide energy. The nitrogen is incorporated in urea, a waste product which is excreted by the kidneys.

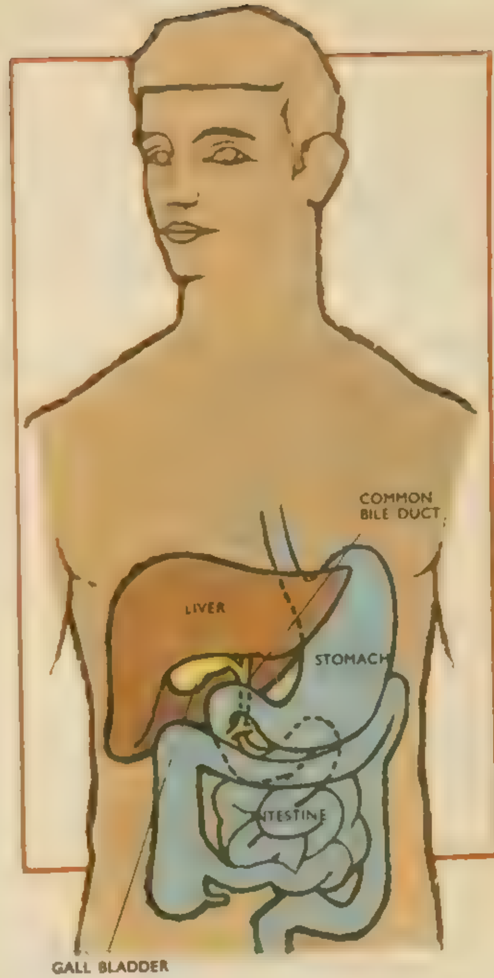
The liver is strategically placed in relation to the gut and the blood supply it receives from there. The gut itself has a rich blood supply to absorb the digested food. Blood rich in food molecules is carried by the *hepatic portal vein* to the liver before it reaches the main circulation. The liver, by a multitude of chemical processes, is then able to act on the food before releasing to the tissues the substances that they require. This is part of the way in which the liver controls the composition of the blood.

Sugar molecules are either built up into large glycogen molecules and stored in this form or they are passed to the tissues when required. Similarly fatty acids are built up into fat or oxidized to supply energy to power other chemical processes or to supply heat. The smaller molecules produced can be reassembled to make glycogen. So fats can be converted into carbohydrates.

Bile produced by the liver cells is stored in the gall bladder. It is released when food enters the small intestine, acting on fats by reducing the surface tension on large droplets (see Hydrolysis) so breaking them up into smaller ones which the fat-digesting enzymes can handle.

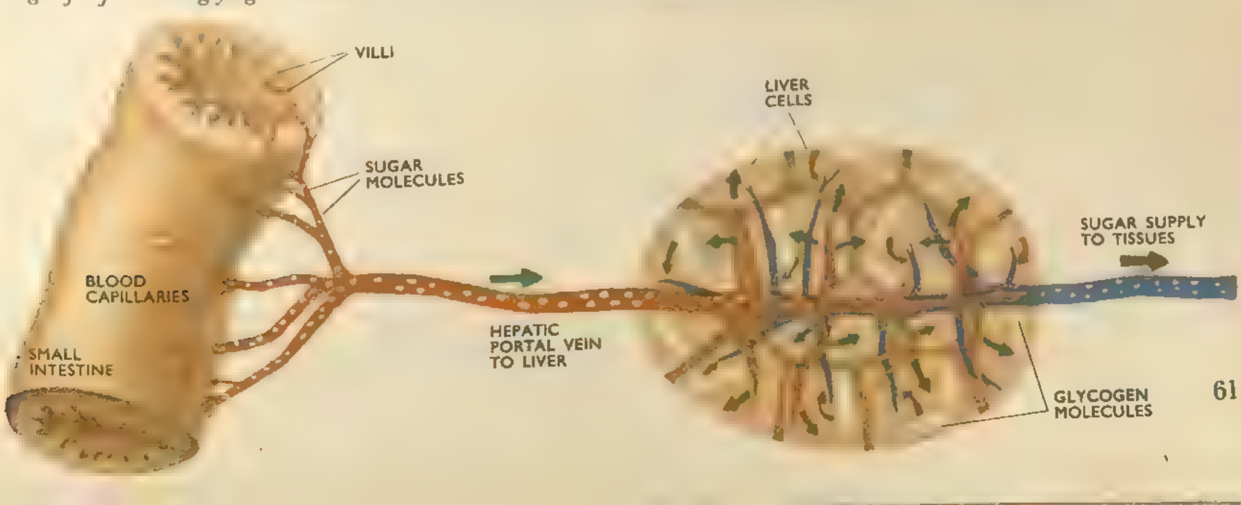
The liver, therefore, is primarily a 'sorting office' between blood from the intestine rich in food and the rest of the circulation. But it is not merely able to control the quantity of substances in the blood leaving it, it is also able to regulate the composition.

The liver's other roles include the breakdown of harmful or *toxic* substances such as alcohol, the removal of dead bacteria from the blood, the manufacture of vitamin A, the storage of iron and copper and the production of heat to help maintain the high body temperature.



A diagram showing the position and relative size of the liver in the human body.

A diagram summarising the main function of the liver. Digested food is absorbed through the wall of the intestine and carried via the hepatic portal vein to the liver. The vein breaks down into tiny channels called capillaries. Glucose (sugar molecules) pass out of the blood vessels into the liver cells where they are built up into large glycogen molecules and stored in this form. When the body requires sugar for fuel these glycogen molecules are broken down into sugar which is carried out of the liver in the blood system.



How insects feed

The mouths and jaws of different types of insects vary considerably according to the food they eat.

Biting and sucking mouths are the two basic types but there are many variations. The first insects are believed to have had simple biting jaws from which all the variations have arisen.

Insect mouthparts or jaws are not internal structures like human jaws: they are paired outgrowths from the head. The mouthparts are, in fact, limbs that are modified for feeding. Their general structure is seen in the cockroach. In front of, or above, the mouth is the upper lip (*labrum*). This is the front part of the head. Around the mouth are the jaws (*mandibles*). These are equipped with sharp ridges and are used for cutting and crushing the food.

Behind or below the jaws are the secondary jaws (*maxillae*). They carry sensitive palps that help to taste the food while the inner parts help in holding it and cutting it up. The lower lip (*labium*) lies just behind the jaws and it, too, helps to hold food. Its palps are also sensitive to touch, taste and smell.

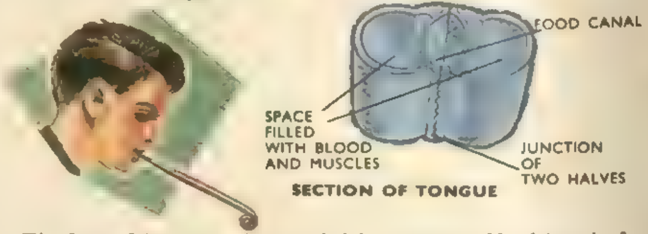
A tongue-like structure on the floor of the mouth completes the mouthparts of the cockroach. This is the *hypopharynx* and a duct of the salivary gland opens at its base. It is not very important in the cockroach but it plays a large part in the working of some sucking mouths.

Biting mouths are found in grasshoppers and locusts, earwigs and dragonflies. They also occur in ants, wasps and all beetles, in a modified form.

All true bugs and flies, as well as most butterflies and moths, have sucking mouths but the actual structure of the mouthparts varies a lot. Some (e.g. bugs) are able to pierce animal or plant tissues to obtain liquid food. Others (e.g. the housefly) are able only to suck up liquids from the surface. These sucking mouths are all formed, however, by modification of some or all of the basic mouthparts shown in the cockroach.

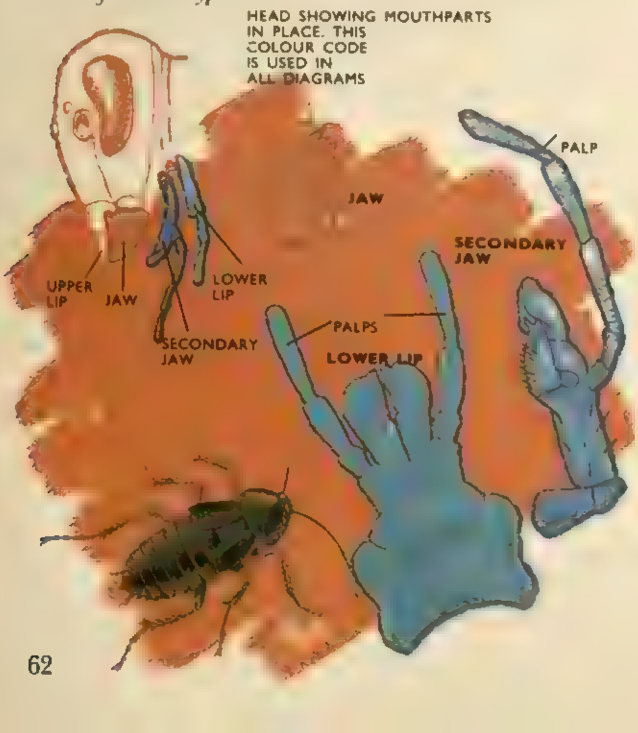
Almost all of the above sucking insects are liquid feeders mainly feeding on the nectar of flowers. The jaws are usually missing and the secondary jaws are greatly altered to form the long coiled 'tongue'. This is especially well developed in the hawk-moths, which can suck up nectar from very deep-throated flowers. The tongue (*proboscis*) is made up of two hollowed parts that are held together by hooks to form a tube.

When not in use it is coiled up, rather like a watchspring, underneath the head. It seems that the insect increases the blood pressure in the tongue and it unrolls rather like a toy paper 'snake' that unrolls when blown into. Muscles inside the



The butterfly's tongue is uncoiled by pumping blood into it. It is coiled up again by muscular action.

The biting mouthparts of the cockroach are thought to be like those of the first insects and all other insect mouthparts can be derived from this type.



tongue contract and coil it up again after feeding. The outer walls contain hundreds of tiny stiff rings separated by narrow membranes. Without these membranes the tongue would be rigid and unable to coil. The front part of the food canal acts as a pump to suck the nectar up the tongue and into the mouth. The replacement of the hard biting jaws of a caterpillar by the elaborate sucking tongue of the butterfly is quite incredible.

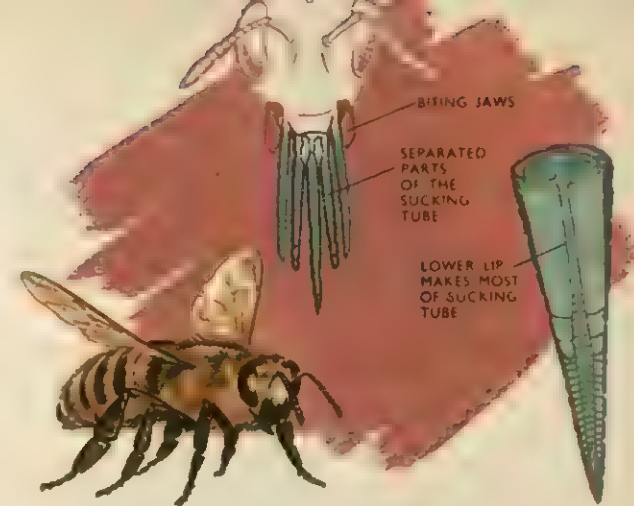
All the bugs have sharp piercing mouthparts through which they suck up plant or animal juices. A heavy infection of aphids (greenfly) can severely weaken a plant.

The jaws and secondary jaws are developed as fine needle-like bristles which surround two canals. When not in use they lie flat under the head, partly sheathed in the lower lip. When the insect begins to feed the sheath is curved or partly withdrawn into the body and the 'needles' are plunged into the host. Muscular action pumps sap or blood up into the mouth through one tube while saliva flows down the other and into the host. The saliva may help to digest the food or, if the insect is a bloodfeeder, it may prevent clotting.

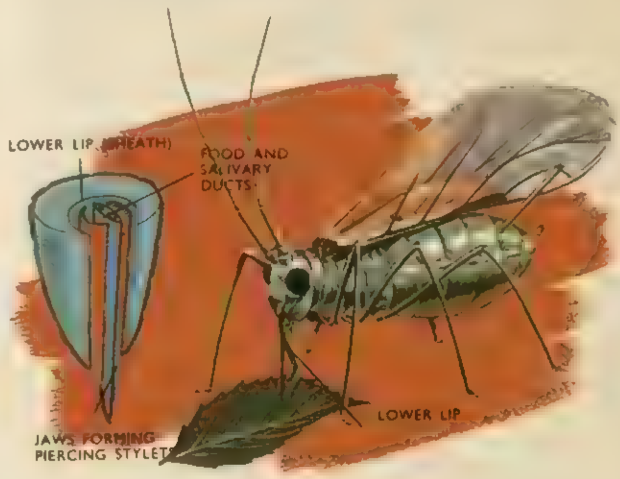
The blood-sucking flies, such as the mosquito, feed in much the same way as the blood-sucking bugs. The mouthparts of the female mosquito consist of a sucking tube (upper lip and hypopharynx) and four 'needles' all enclosed in the sheath of the lower lip. The four 'needles' represent the jaws and secondary jaws. They and the sucking tube pierce the skin and blood is drawn up. Saliva enters the wound through a canal in the hypopharynx and it is in this way that an infected mosquito may transmit malaria to the person it has bitten. The male mosquito feeds on nectar.

The housefly and many other flies feed on surface liquids. The sucking mouth is unlike that of other insects. There is a large fleshy *proboscis* formed from the lower lip and it widens into the lobes which are crossed by numerous tiny canals. Saliva is poured down these and onto the food to dissolve it. The liquid is then sucked up into the mouth. The jaws and secondary jaws are missing.

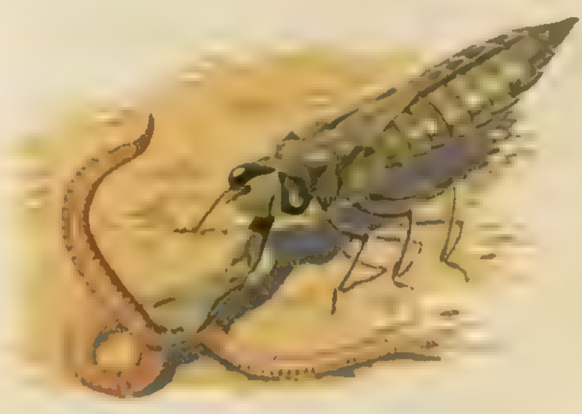
Worker bees collect two types of food for the colony—pollen and nectar. Pollen is usually collected on the legs and body while the bee is searching. Nectar is sucked up from the nectaries of flowers through a sucking tube formed from the lower lip. The secondary jaws are sheath-like and protect the base of the tube. Unlike other sucking insects, the bees have functional jaws. These are strongly toothed and assist in making the cells of the comb. In the leaf-cutter bee they are used for cutting leaves with which the nest is lined.



The honeybee has both sucking and biting mouthparts although it feeds on liquid nectar.



An aphid feeding. (left) An enlarged drawing of the mouthparts which form the piercing and sucking organ.



The lower lip of the young dragonfly is large and hinged. It is shot out to catch prey in the sharp pincers at the end.

Hydra

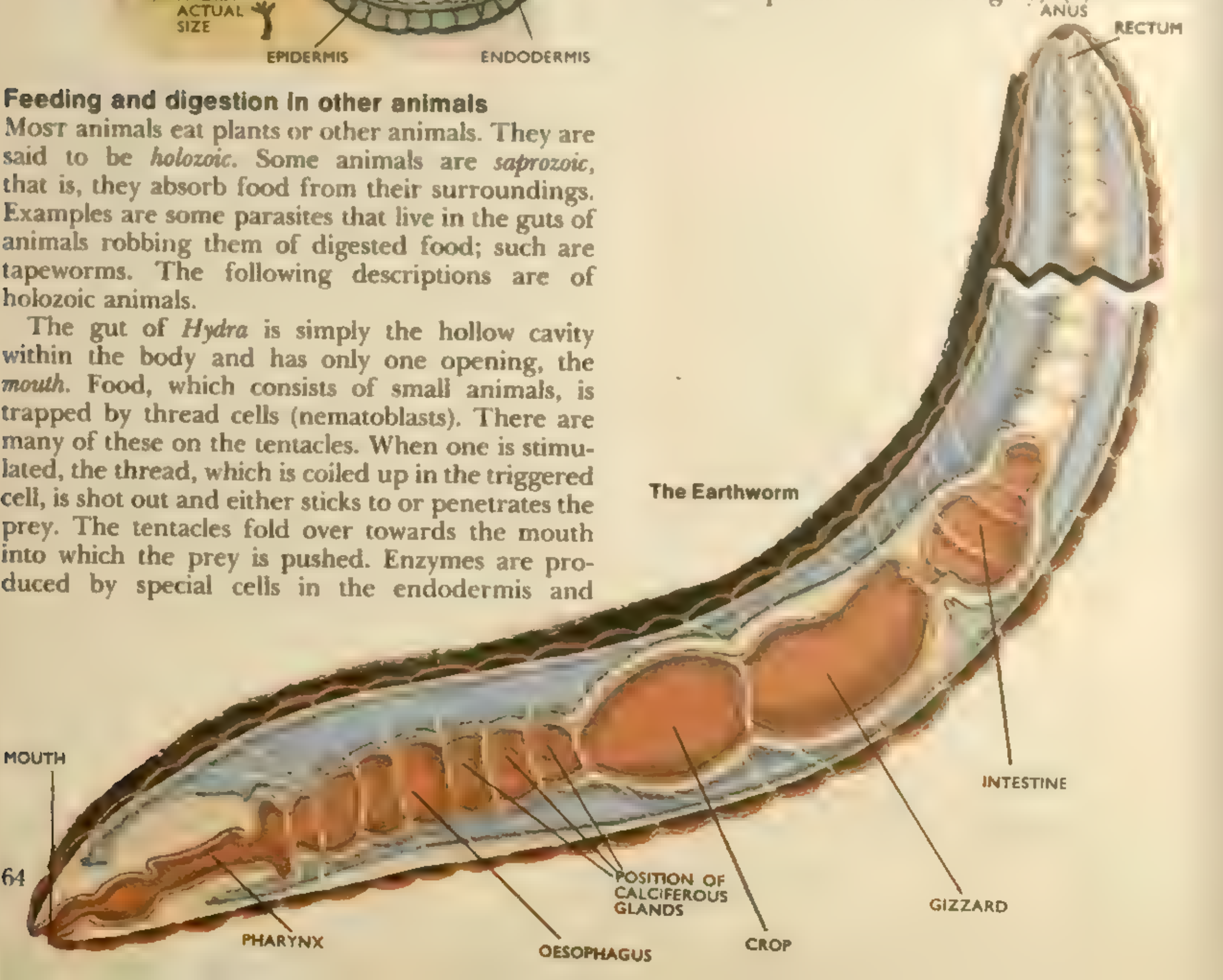
Feeding and digestion in other animals

MOST animals eat plants or other animals. They are said to be *holozoic*. Some animals are *saprozoic*, that is, they absorb food from their surroundings. Examples are some parasites that live in the guts of animals robbing them of digested food; such are tapeworms. The following descriptions are of holozoic animals.

The gut of *Hydra* is simply the hollow cavity within the body and has only one opening, the *mouth*. Food, which consists of small animals, is trapped by thread cells (nematoblasts). There are many of these on the tentacles. When one is stimulated, the thread, which is coiled up in the triggered cell, is shot out and either sticks to or penetrates the prey. The tentacles fold over towards the mouth into which the prey is pushed. Enzymes are produced by special cells in the endodermis and released into the gut cavity. Digestion proceeds a little way. It is completed inside the cells in food vacuoles. The prey is engulfed in the same way that *Amoeba* catches its food. Undigested food is passed out of the cells into the gut cavity and from there to the outside through the mouth.

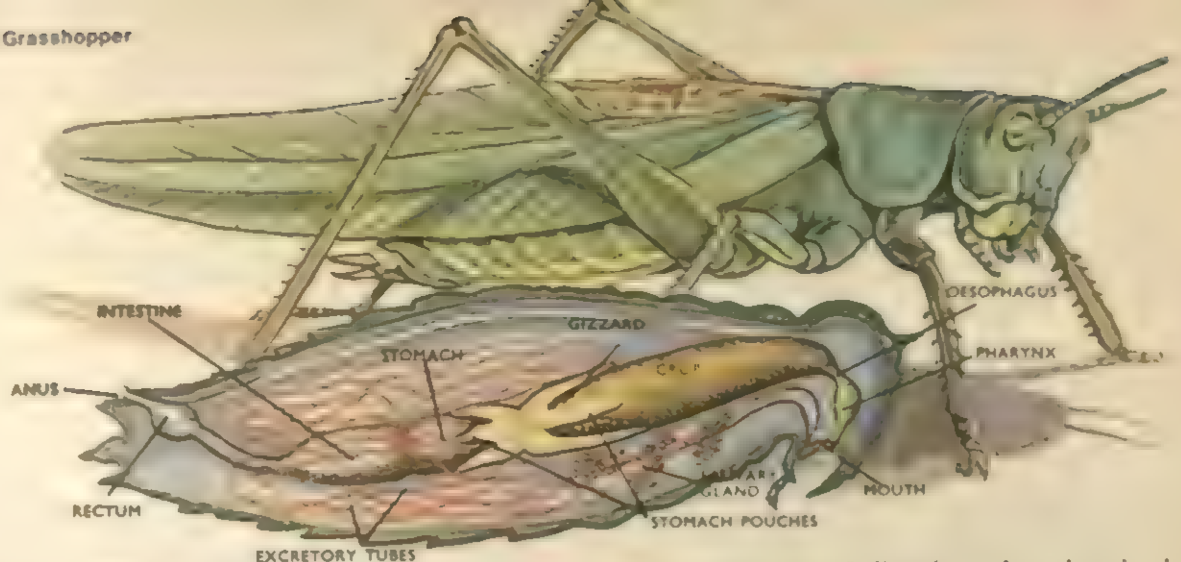
Digestion in *Hydra* therefore can be divided into two phases, the preliminary digestion outside the cells of the endodermis (this is said to be *extra*cellular), and the secondary phase inside the cells. This is said to be *intra*cellular. Digestion is completed within the cells. In all coelenterates (corals, hydroids, jelly-fish, sea anemones, etc.) digestion is partly extracellular and partly intracellular.

In the earthworm and more complicated animals the gut has two openings, the mouth at the front and the anus at the rear. The gut, generally speaking, can be divided into five main regions: (1) the *mouth*, and the part of the gut behind it, which is called the *pharynx*: (2) the *oesophagus*—part of this may sometimes be modified to form a chamber—the *crop*: (3) the *stomach*—this is where the major part of the digestive process starts (part of the stomach—the *gizzard*—may be muscular and used to break the food up and mix it thoroughly): (4) the *intestine*—



The Earthworm

The Grasshopper



where in special pouches digestion is completed and the food is absorbed: (5) the *rectum*—where water is often absorbed in large quantities and undigested remains are compressed to form the faeces.

The earthworm can eat its way through the soil taking this in through its mouth. Plant material is also eaten. As it is moved back along the alimentary canal food is extracted from it. Glands in the canal walls provide mucus to lubricate and moisten the food and an enzyme that breaks down proteins. The muscular pharynx swallows the soil and from there it passes down the oesophagus. The crop beyond the oesophagus is a thin-walled structure. The food does not remain long there before passing into the gizzard, an enlarged, muscular part of the gut. This grinds the food up, an action which is aided by the presence of any small grit particles. The food passes from the gizzard into the intestine, a long tube which continues back to the anus. In the intestine enzymes are released onto the food by gland cells. A large fold in the roof of the intestine wall increases the area through which digested food can be absorbed.

In insects the gut is complicated. In the grasshopper, for example, food is taken in through the *mouth*. The salivary glands pour a fluid onto it. The *pharynx* leads with little obvious change in structure into the *oesophagus*—a narrow tube that continues into a large thin-walled *crop* where the food may be stored temporarily while saliva acts on the food. Ridges on the inside of the crop wall help to break up the food into small fragments. The *gizzard* beyond the crop is muscular. It is lined with horny teeth and these break down the food even more. A valve at the hind end of the gizzard prevents the food from passing into the *mid-gut* until it has been thoroughly ground up.

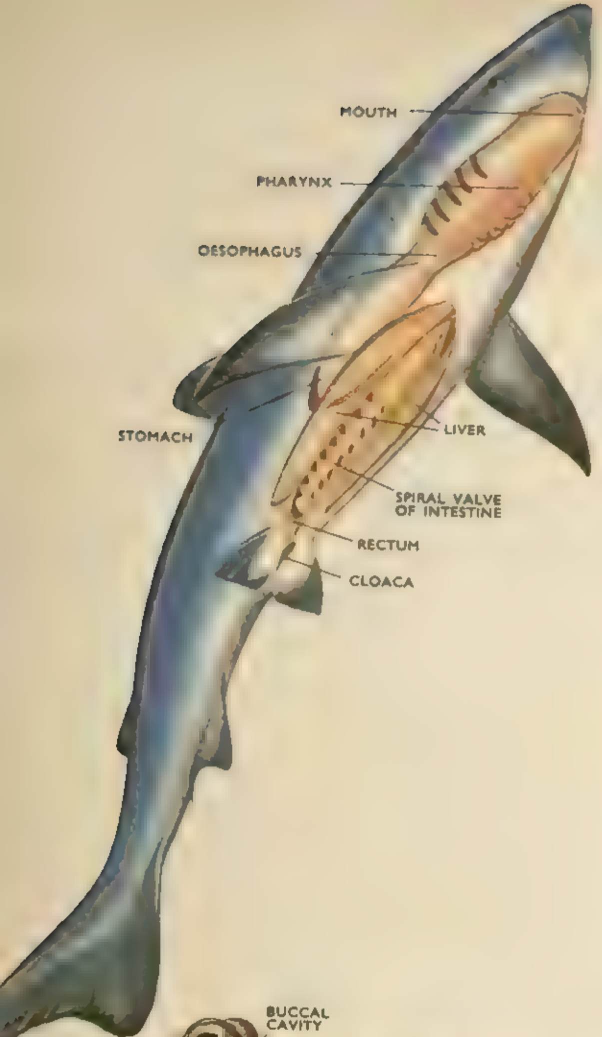
The major part of digestion takes place in the mid-gut. Digestive juices are released from glands lining several pouches that arise from the front end of the mid-gut. These pouches also aid in absorption.

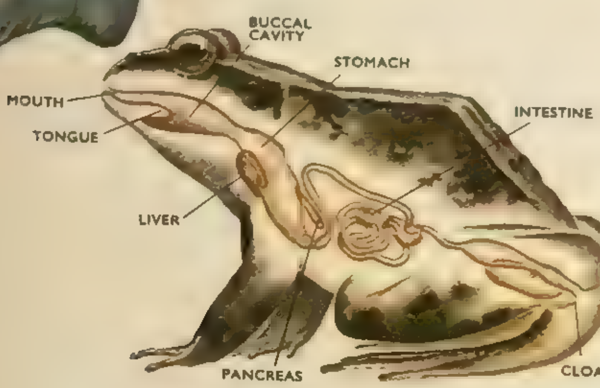
The *intestine*, beyond the mid-gut, is lined with cuticle. Undigested food passes along it and out through the *anus*, having received waste material from the 'kidney' tubules on the way. In many insects there are special devices for absorbing water from the undigested food. Conserving water is a considerable problem amongst land-dwelling animals.

In sharks the digestive system is basically similar to that of other vertebrates with jaws. Prey is seized in the *mouth* and prevented from escaping by rows of sharp backward-pointing teeth. Glands lining the *pharynx* (the cavity behind the mouth) produce mucus which moistens the food and aids its passage down the *oesophagus* to the *stomach*, a large sac. Pepsin and acid are produced in the stomach. A ring of muscle controls the outflow of partly digested food from the stomach to the *intestine*. The bile duct and pancreatic duct open into the first part of the intestine. This is a stocky organ containing a spiral valve which increases its effective length and the surface area through which the absorption of digested food can take place. The *rectum* is very short and undigested food passes along it and out of the body, together with the urine, by way of the *cloaca*.

The details of digestion in bony fishes are similar to those of sharks. There is no spiral valve but the intestine is often long and coiled and its internal surface may be ridged.

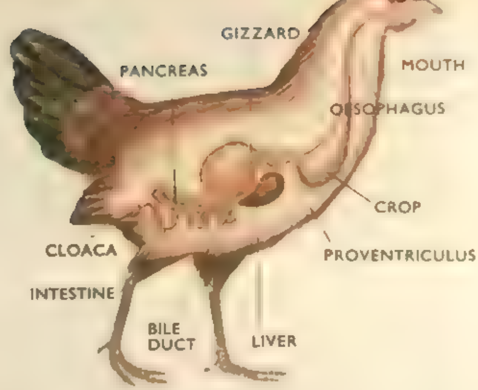
In amphibians, such as the frog, juices similar to those in man are poured onto the food though there are no salivary glands and no digestion takes





place in the mouth. This is also the case in fishes. Adult frogs live mainly on insects, flicking out the sticky tongue which is attached to the floor of the mouth.

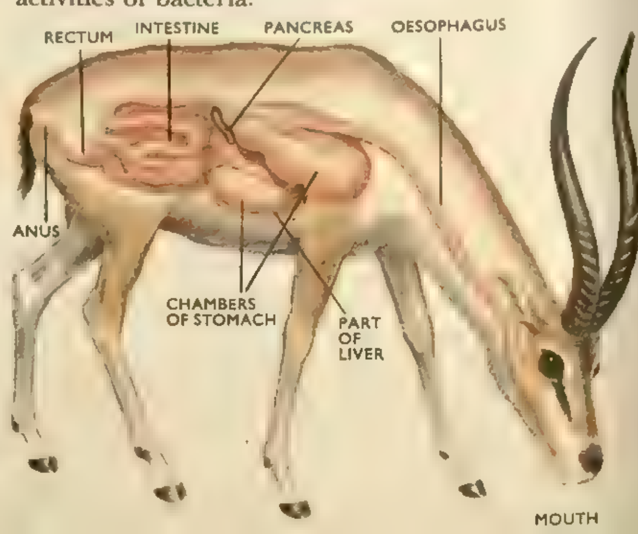
The gut of birds, which have no teeth, is different from that of mammals. Saliva is poured onto the food in the *mouth* and it is swallowed down the *oesophagus* and into the *crop*. This is often large, particularly in birds that eat grain, and the food



is partly broken up by its storage there. The *stomach* is divided into two parts, the *proventriculus* and the *gizzard*. The former produces enzymes, and the food, which is then thoroughly moistened and partly broken down, is ground up in the gizzard which has a thick, powerful and muscular wall. In carnivorous birds the gizzard is less muscular. Bile and the pancreatic juices are poured onto the food in the *small intestine*. The *cloaca* is divided into chambers and much of the water in the faeces and from the urine is absorbed there.

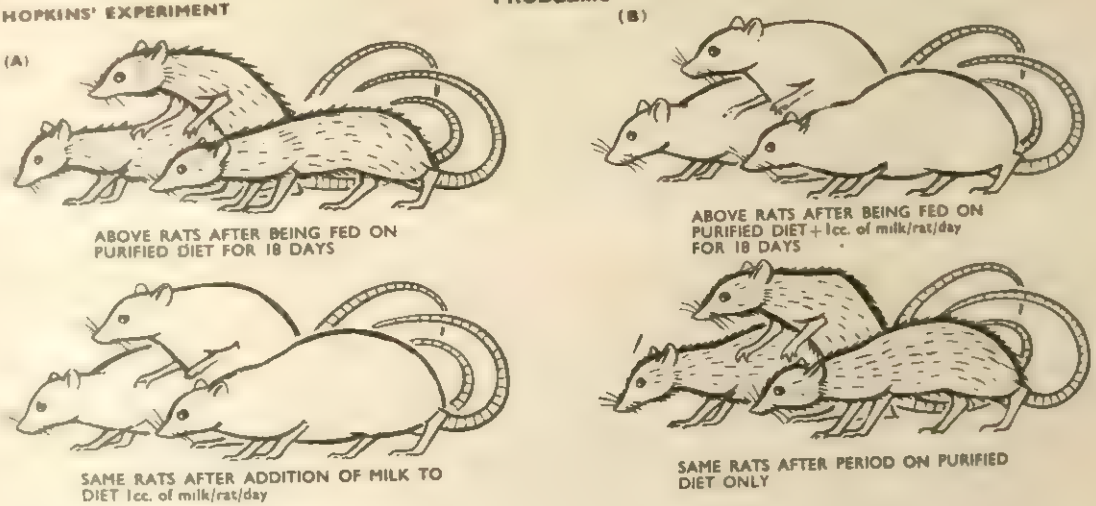
Amongst mammals, the ungulate (hoofed) mammals are interesting in that parts of the gut are specialised as chambers in which the cellulose of plant food can be broken down by the activities of bacteria. In horses, the caecum is modified, but in cows the stomach is modified. In the cow, for example, the stomach is a large four-chambered organ. Food is eaten and swallowed. It passes down the oesophagus to the first chamber of the stomach. From time to time it is brought up and chewed—a process that is commonly termed 'chewing the cud'. It is then swallowed again, whence it passes into the other chambers in turn where it is acted upon by bacteria.

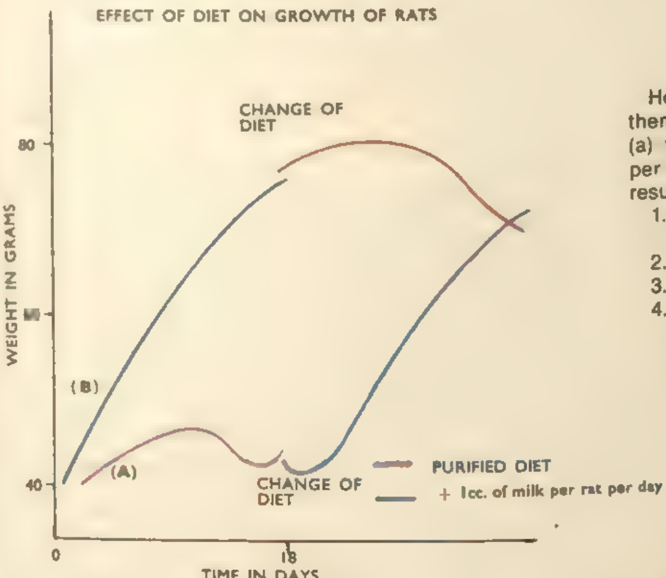
Very few animals produce an enzyme that is able to break down cellulose. They must rely on the activities of bacteria.



PROBLEMS

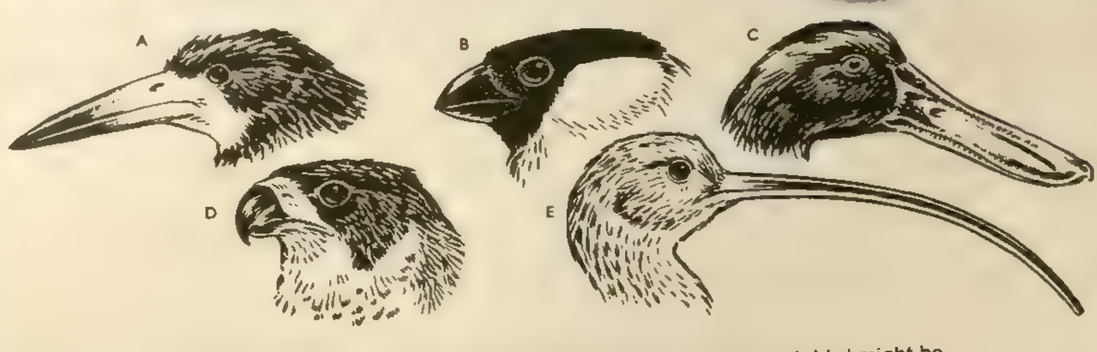
HOPKINS' EXPERIMENT





Hopkins took the young of several pairs of rats and mixed them up before dividing them into two equal groups Group (a) were fed on a purified diet, group (b) had milk 1 cc. per rat per day added. The graph summarises the results.

1. Why did he mix the rats up before dividing them into two groups?
2. What does the first part of the experiment suggest?
3. Why does the second part confirm this?
4. Analysis shows that milk consists almost entirely of the substances that the purified diet contains, yet group (a) develop deficiency symptoms. Explain this.



Look at the drawings and suggest what the principal diet of each bird might be.

Breathing and Respiration

In science facts are learned by looking at things, making observations, by thinking about the observations, trying to find connections between one observation and another, by asking questions to be answered by more observations, by inventing theories (intelligent guesses or hypotheses), and by devising experiments which can prove or disprove theories.

The pages which follow contain factual information which has been obtained in this way. Some theories are presented as well. It is not always easy to distinguish, in an account of such a subject as breathing and respiration, between facts which are known for certain and theories which may still have to be modified when new facts are learned. The important question for the reader to keep asking is, how do we know? or how could we find out?

It is interesting and profitable to put yourself in the position of the investigator, to observe, to ask questions, to devise experiments, even to invent hypotheses. This is the object of this practical introduction.

A practical introduction—breathing in man

Observation 1. How many times do you breathe per minute?

Question. Under what circumstances does your rate of breathing increase?

Hypothesis. Several possible causes of increased breathing rate might be put forward, e.g. increased rate of breathing is caused by a rise of body temperature, by an increased rate of heart beat, by increased physical activity, by excitement. Try to decide which of these is most likely and explain why.

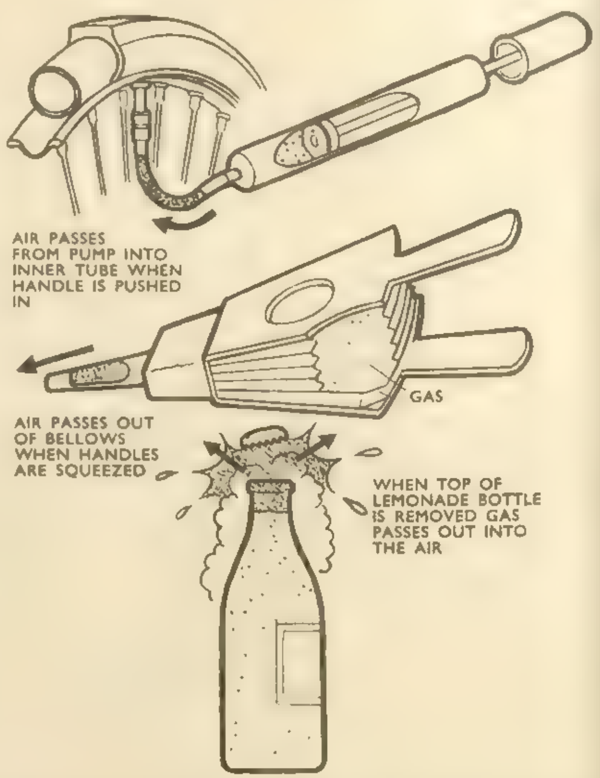
Observation 2. How much air do you exchange at each breath? What is the greatest volume of air you can breathe out after a normal inspiration?
Discuss ways in which the practical problems of making these measurements could be solved. Devise methods. How accurate a measurement do you think you can make?
(Hint: You may find polythene bags useful in this experiment, under the supervision of your teacher.)

Question. Is there any connection between these measurements and a person's height or 'cross-country' performance?

Question. Where does air go when it is breathed in?

Observation 3. Examine fresh sheep's lungs, and answer the following questions.
How many lungs are there?
How are the lungs connected to the mouth?
What prevents the connecting tube from collapsing?
Is there any food in the tube? What prevented food from entering the tube?
What do you think gives the lungs their pink colour?
Why pink, not red?
If you insert a rubber tube down the trachea and blow down it, what happens?
What does this tell you about the lungs?
When you stop blowing, what happens?
What does the observation tell you?
When the lungs are caused to expand, they go paler; try to explain why.
If you cut a slice of one of the lungs and look at the cut end what can you see?
Squeeze the lung at the cut end. What do you see now?
Put the slice you removed under water and squeeze. Explain your observations.

Question. What causes air to go into and come out of the lungs?
This question does not only concern lungs and air, it is one example of a general question, namely, what causes a fluid, in this case gas, to move from one place to another? Think of three other cases: a. Air goes from a bicycle pump into a tyre when the pump handle is pushed in. b. Air passes from a bellows when they are squeezed. c. When the top is removed from a lemonade bottle the gas passes out into the air. What have these situations in common? What causes the gas to move from one place to another?



Question. What do you know about the air pressure in your lungs compared with the air pressure outside, when you breathe out, when you breathe in?

Observation 4. Examine the thorax of a freshly killed rat with the skin removed and then with the thorax opened, from the under side. Describe its structure. Compare the structure of the thorax with the structure of the model (see right). Decide, a. what each part of the model represents, b. which parts of the thorax are not represented.

Hypothesis by model making.

If the rubber sheet on the model is pushed up, the balloons collapse. Explain, step by step, what happened between the rubber sheet going up and the balloons collapsing. What does the manometer tell us?

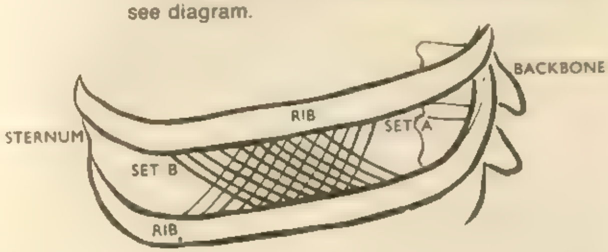
Now pull the sheet down and again explain step by step what caused the air to enter the balloons.

Part played by the ribs.

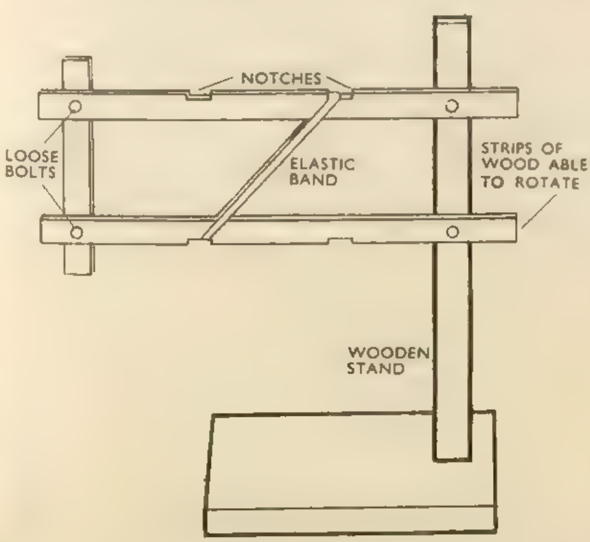
Observation 5. Hold your ribs with your finger tips. Take a deep breath in (inspiration). What happened to your ribs?

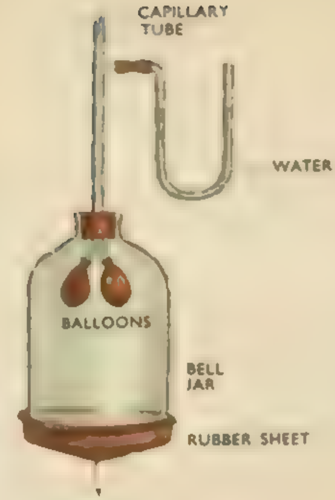
Hypothesis by model making.

Make a rib model. In the intact animal each rib is a curved bone joined by a two-headed moveable joint to the vertebral column behind, and by springy cartilage to a thin strip called the sternum in front. There are two sets of muscle fibres connecting each rib to the ribs above and below—see diagram.



It is not easy to understand what these muscles do when they contract. Try making this model and then suggest how these muscles may help during breathing.





Respiration

Observation 1. The percentage of oxygen in inspired air is about 20%, the oxygen percentage in expired air is about 17%.

One of the practical problems which physiologists have to overcome is that of variation of their results. It is rare to get exactly the same result of any measurement time after time. It is quite possible for you to measure the percentage of oxygen in the air in your school laboratory fairly accurately, but you will not all get exactly the same result. In order to illustrate and deal with this variation tackle the following problem which cropped up in a school laboratory.

Using a simplified version of the apparatus shown in top illustration page 70, in which the plastic screw had been replaced with a short length of glass rod, the results given below were obtained after two practice runs.

Results obtained in 25 trials with this apparatus are given below.

Oxygen in inspired air

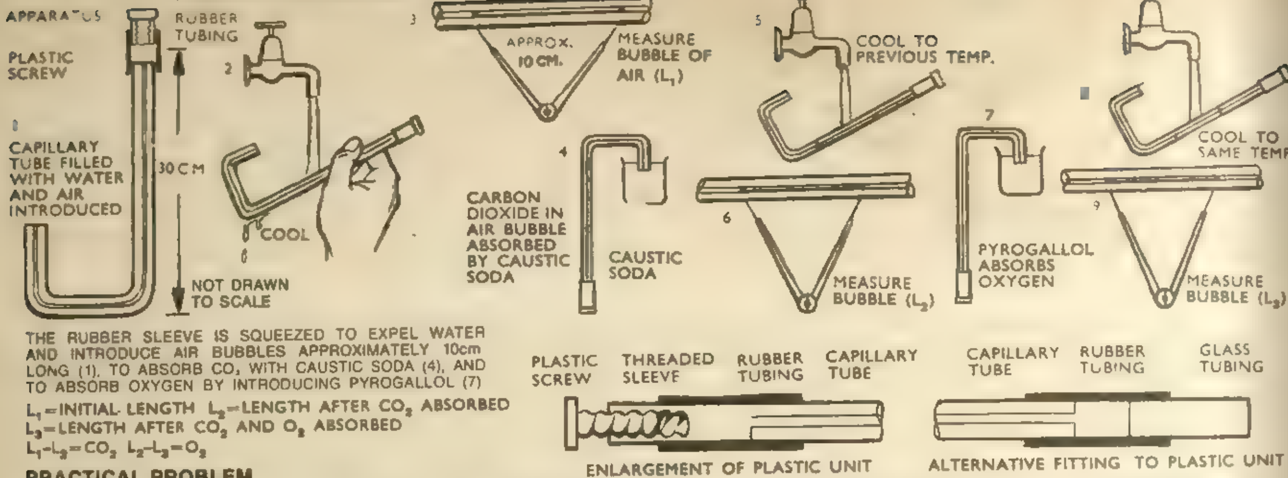
Trial No.	*% Oxygen*	*Trial No.*	*% Oxygen*
1	19·0	13	19·8
2	18·0	14	22·5
3	18·6	15	19·3
4	20·0	16	20·7
5	17·7	17	21·5
6	20·7	18	20·7
7	19·2	19	20·7
8	19·6	20	18·0
9	21·4	21	18·2
10	21·4	22	19·0
11	20·0	23	20·7
12	20·0	24	18·0
		25	18·0

One boy had time to collect some expired air and measure the oxygen content of expired air and found it to be 17·6%. Are we safe in concluding that expired air contains less oxygen than inspired air?

Suggestions: Find the average result, find the limits, i.e. the largest and smallest results, plot a block diagram (histogram) to get a picture of the way in which the results vary.

Observation. The following table gives a comparison of the differences between inspired air and expired air.

A METHOD OF GAS ANALYSIS



PRACTICAL PROBLEM

The percentage of oxygen in inspired air can be measured by the use of the apparatus illustrated above. A bubble of air is introduced into the tube which is full of water. The bubble is cooled to the temperature of tap water and the bubble's length measured. Sodium hydroxide is now introduced into the tube in order to absorb the carbon dioxide present and the bubble again cooled and measured. Now alkaline pyrogallol is introduced into the tube to absorb the oxygen and the bubble again cooled and measured.

Given L_1, L_2 and L_3 how can the percentage of oxygen in inspired air be calculated?

To measure the percentage of oxygen in expired air the method is the same but it is of course necessary to first collect the expired air before sampling it and analysing it. Carbon dioxide is soluble in water so it is necessary to devise some means of collecting expired air so that it does not have contact with water.

Suggest a means whereby expired air could be collected for analysis.

(Hint: carbon dioxide is not soluble in concentrated common salt solution.)

Content of inspired and expired air

	Inspired air	Expired air
Nitrogen	79% approx.	79% approx.
Oxygen	20% approx.	17% approx.
Carbon Dioxide	0·03%	4% approx.
Water Vapour	A variable amount	Always saturated
Temperature	At air temperature	Always nearer to 98·4°F.

Conclusions. Study the information in the above table, then answer the question.

Which of the following statements follow, *from the information in the table*?

a. The human body makes carbon dioxide.
b. Human beings breathe in oxygen, and breathe out carbon dioxide.
c. Human beings must take in substances containing carbon.
d. Human beings release water from substances they take in.
e. The human body releases energy as heat.
f. Under normal conditions nitrogen does not enter the blood stream from the lungs.

Muscle respiration

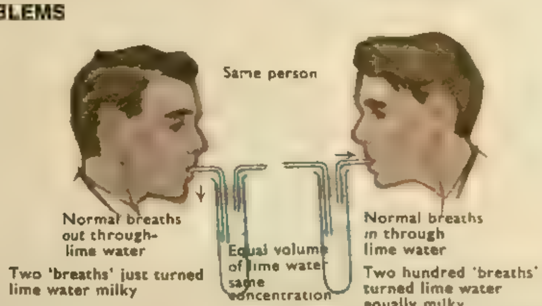
Read the following pieces of experimental evidence. Study each carefully and after each state briefly what each tells you.

Evidence a. If a muscle is removed from a freshly killed animal and a weight is suspended from it, it can be made to shorten and lift the weight.

Evidence b. The way in which the muscle is made to contract is by giving it small electric shocks. The muscle will contract repeatedly for a time but after a number of contractions fails to respond to the shocks. In air or in pure oxygen after a rest period it recovers its ability to contract. In pure nitrogen it fails to recover.

Evidence c. The blood flowing into and flowing out of a muscle intact in the animal has been analysed to find out how much carbon dioxide it contains. In an active muscle the blood flowing out con-

PROBLEMS



1. Which contains most carbon dioxide, inspired or expired air?
2. Write down the fraction of $\frac{\text{carbon dioxide in expired air}}{\text{carbon dioxide in inspired air}}$ and so calculate how much more carbon dioxide is present in one compared with the other.
3. Why was it necessary to use the same volume and the same concentration of lime water in each case, and the same person?
4. What does this experiment tell us about a chemical process taking place in the body?

N.B. AS AN ALTERNATIVE TO LIME WATER USE VERY DILUTE CAUSTIC SODA AND ADD 1 DROP OF PHENOL PHTHALEIN INDICATOR TO EACH TUBE. THIS IS EXTREMELY SENSITIVE TO LOW CONCENTRATIONS OF CARBON DIOXIDE

tains more carbon dioxide than the blood flowing to the muscle

The difference in carbon dioxide content is less if the muscle is not active.

Evidence d. The blood flowing into an active muscle contains more sugar but less lactic acid than the blood flowing out of it.

Evidence e. If the blood supply to a muscle is cut off by closing the artery to the muscle, the muscle fatigues (i.e. ceases to be able to contract) much quicker than when the blood supply is normal. The muscle recovers when the blood supply is restored.

Evidence f. If sugar is burnt in air, oxygen is used and carbon dioxide produced. Heat is also produced.

Now summarise all the information you have obtained from this evidence. Look for possible connections. Complete the following hypothesis by filling in the blanks.

Muscles are capable of doing . . . . . They therefore require a supply of . . . . . We know that. . . . . contains energy because when it is burnt . . . . . is released. The fact that the blood going to an active muscle contains .... than the blood coming out of the muscle suggests that the energy for muscle action may also come from sugar. The failure of muscles to recover unless .... is present may mean that in order to release the .... from .... oxygen is required. The muscle while releasing energy also makes ....

We may therefore summarize the events taking place in an active muscle as

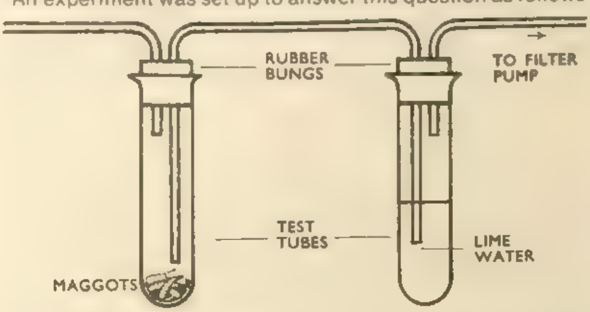
. + ... = ... + ...

Which observed fact is not explained in this hypothesis?

Respiration in other animals

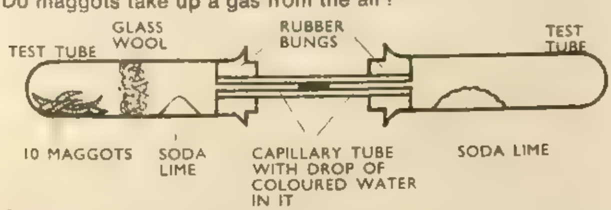
Do blow-fly maggots respire?

An experiment was set up to answer this question as follows:



The lime water went milky after 4 hrs. This does *NOT* tell us that maggots give off carbon dioxide. How would you redesign the apparatus to answer the question?

Do maggots take up a gas from the air?



Soda lime absorbs carbon dioxide.

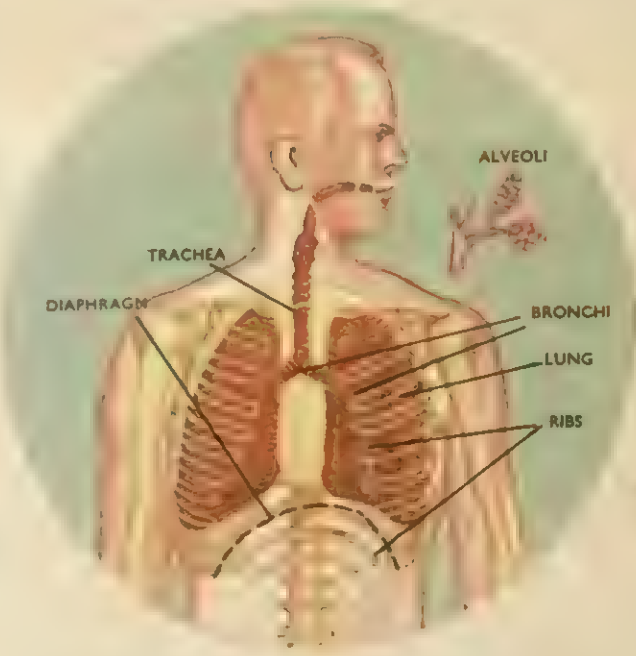
Set up the apparatus and find out what happens.

Practical Hint: Avoid handling the tubes more than is strictly necessary, and also leave the tubes ready but disconnected for five minutes before connecting to the capillary.

Questions. Do the maggots absorb a gas?

What is the purpose of having two tubes connected in this way?

Could you find out how much gas the maggots absorb per hour in this way?



The structure of the human breathing system. Inset: several lung tubes (bronchioles) *showing the tiny clusters of air sacs or* alveoli.

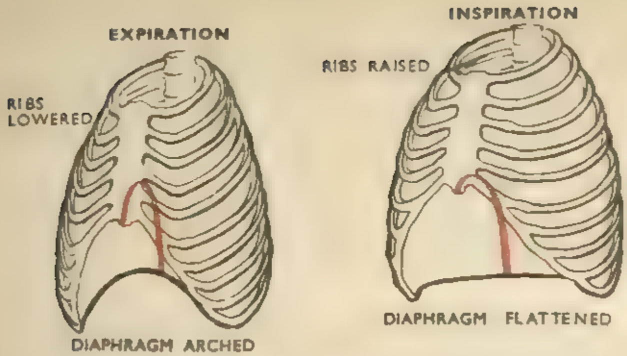
Growth and movement, in fact *all* living processes, require energy. This is obtained by the burning or *oxidation* of food materials within the body cells. In all animals and in the majority of plants the process depends on oxygen obtained from the surroundings, whether this is air or water.

The composition of air

The atmosphere is a mixture of gases consisting chiefly of nitrogen (79%), oxygen (20%) and carbon dioxide (0·03%) with varying amounts of water vapour. An air-breathing creature such as man relies on this mixture for obtaining the oxygen that he needs. Analysis of air breathed in and that breathed out shows that the latter contains the same amount of nitrogen, less oxygen—because this is taken away by the tissues—and more carbon dioxide because this is produced by the tissues. The expired air is also saturated with water vapour.

Breathing in man

When an animal is asleep or lying still its breathing movements are perhaps the most obvious sign that it is alive. It is clear from the differences in the

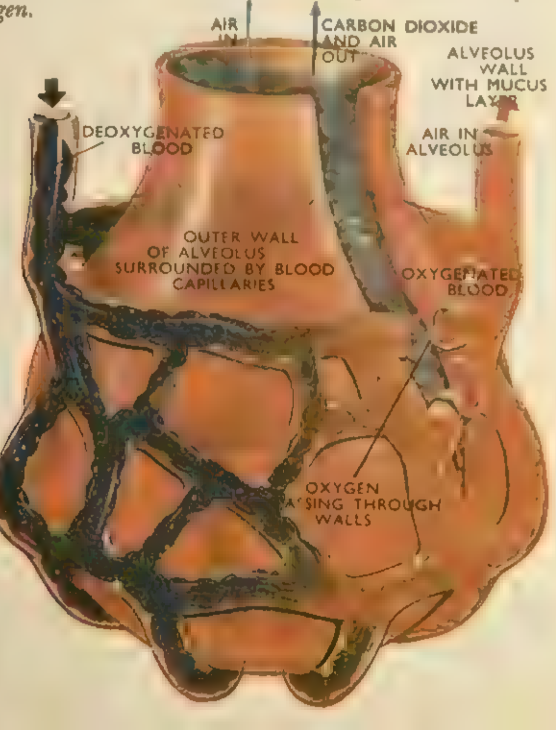


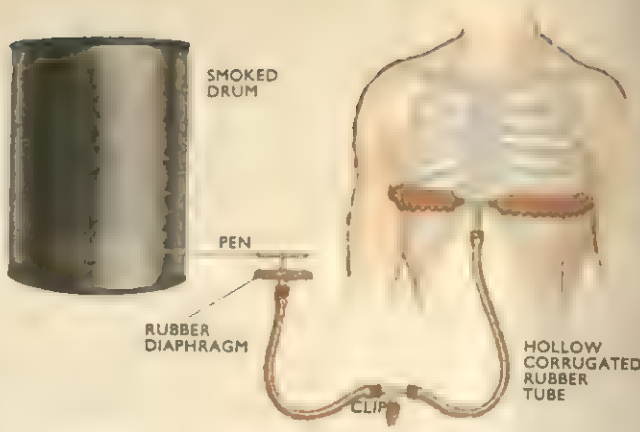
The position of the ribs and diaphragm at inspiration (right) and expiration (left).

composition of inspired and expired air that an important function of breathing is to obtain oxygen. But another essential job is to remove carbon dioxide waste, for if there is too much inside the cells they are poisoned.

The breathing apparatus of a human being consists of an airtight box, the sides of which consist of the *ribs* and its muscles *(intercostals)* and which is closed below by a muscular sheet—the *diaphragm*. Inside the box or chest cavity are the *lungs*. Each lung may be compared with a tree the trunk and branches of which are hollow and represent the *bronchus* (plural *bronchi*) and *bronchioles* respectively; each cluster of leaves represents a cluster of tiny, hollow air sacs—the *alveoli*. Each respiratory tree is enclosed in a layer of tissue—the *pleura*—and all parts of it have a rich blood supply. The two bronchi are branches of the windpipe or

A highly enlarged view of an air sac showing the enveloping mesh of blood capillaries and the exchange of carbon dioxide and oxygen.





PRACTICAL PROBLEM

With the apparatus shown record the breathing movements on the rotating drum. What sort of trace would you expect after vigorous exercise?

---

trachea. The lungs communicate with the outside by way of the windpipe, mouth and nostrils. The alveoli and the bronchioles have elastic fibres in their walls. During inspiration (breathing in) they give allowing the lungs to expand and when they contract (i.e. shorten) during expiration (breathing out) air is forced out of the lungs.

The diaphragm is domed upwards underneath the rib cage. At inspiration its muscle shortens and it is lowered. At the same time one set of rib muscles (*external* intercostals) shorten pulling the ribs outwards. The chest cavity is made larger and so the pressure inside it, which is pressing on the lungs, is reduced. Atmospheric pressure therefore forces air into the lungs. During expiration the *internal* intercostal muscles contract, the diaphragm relaxes and the shortening of the elastic fibres in the lung tissue forces used air out of the lungs.

Although breathing is a rhythmic process it is one whose rhythm can be adjusted to meet the varying demands for oxygen made by the tissues. We breathe much more rapidly and take deeper breaths when running than when walking. The muscles require larger quantities of oxygen when they are working quickly. But it is no use taking more air into the lungs if the oxygen is not transported from there to the tissues more quickly. So the rate at which the heart beats is increased to raise the volume of blood passing through the lungs in a given time and also the speed at which it enters and leaves. The muscles, in using up more oxygen, produce more carbon dioxide waste so that the improvement in breathing and circulation also aids in the efficient removal of larger quantities of carbon dioxide. A human walks in an upright posi-

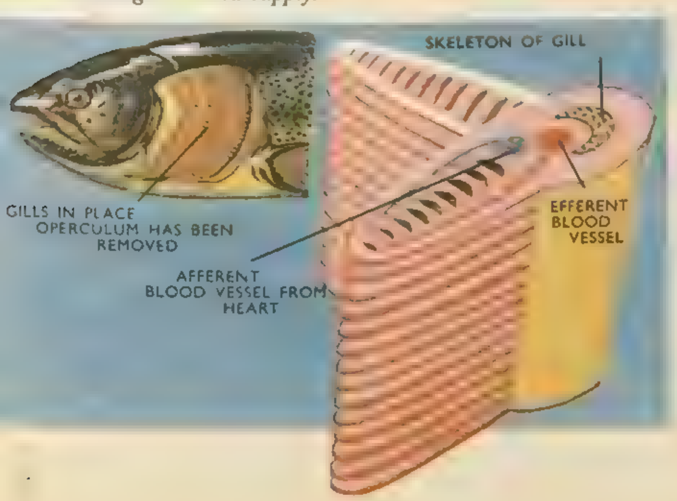
tion so that his diaphragm is more or less horizontal; its movements are vertical therefore. But in animals that walk on all fours (e.g. horses) the diaphragm is vertical; it moves horizontally. The rib cage takes little weight in man so it is able to move easily and either its movements or those of the diaphragm will ventilate the lungs adequately. The rib cage of a horse takes more weight, however, so that the diaphragm is more important in ventilating the lungs. In contrast, whales, and other mammals that live entirely in water and whose weight is supported by the water, can use their chest muscles for breathing so that the diaphragm is much less important. They have to come to the surface to breathe.

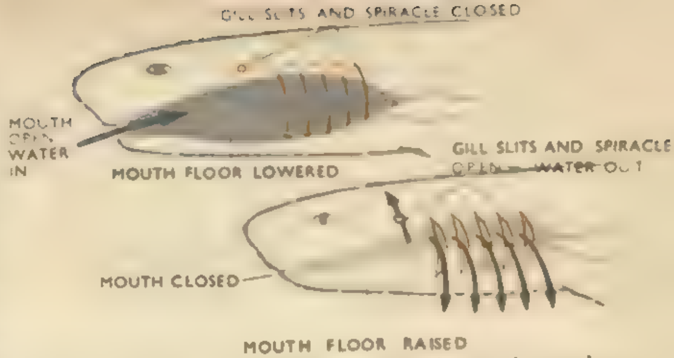
Gills

Many animals that live in water have *gills* which absorb oxygen from the water. The gills of fishes consist of very thin plates of tissue arranged in two blocks—one on either side of the throat. Water is made to pass over them by movements of the throat and mouth. The gill plates have a rich blood supply. Oxygen dissolved in the water passes into the blood, and is transported to the tissues. Carbon dioxide waste passes out of the blood returning to the gills and is washed away by the water current leaving the gills.

Because a continuous stream of water flows over the gills there is always a fresh source of oxygen next to the gills. Air enters and leaves the lungs through the same channel, however, and consequently the internal area of the alveoli is very great to allow for more efficient exchange of oxygen and carbon dioxide.

The gills of a bony fish exposed by removing the gill cover or operculum *and inset (highly enlarged) several gill filaments showing the blood supply.*





Diagrams showing the mechanism by which water is passed over the gills in a shark-like fish.

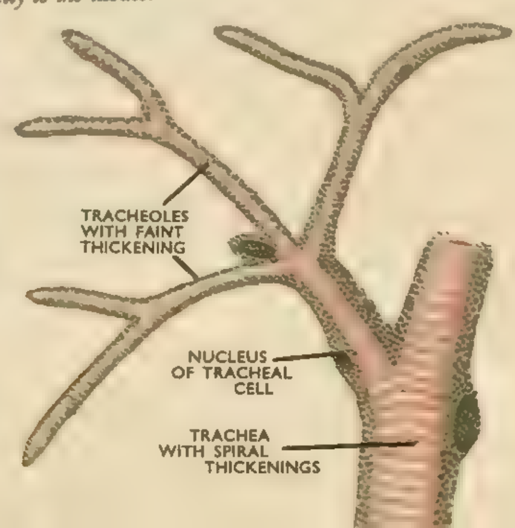
The tracheal system of insects

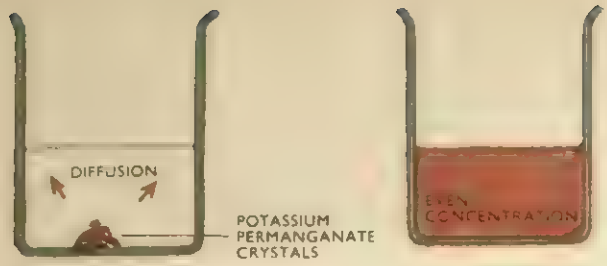
Adult insects breathe air. They have a branching network of tubes *(tracheae)* throughout the body. These are strengthened with hard spiral thickenings which stop them from collapsing. The finest branches are closely connected to the tissues. The tracheae open to the exterior through tiny holes *(spiracles)* along the sides of the body. The very active flying insects (e.g. bees) have air sacs, similar to those of birds, in which air can be stored. Movements of the body help to pump air in and out of the tracheae.

Nature of respiration

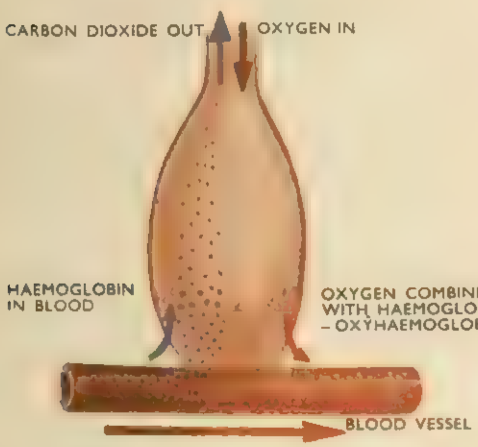
In order to do any kind of work, energy must be expended. The muscles that an animal uses to do mechanical work must have supplies of energy, therefore. It may be that oxygen is in some way concerned with the supply of energy to the muscles. If a muscle is removed from a freshly killed animal it can be made to contract for a time by giving it small electric shocks. Eventually it fails to contract when shocked. But after a rest in oxygen it regains its ability to contract (after resting in nitrogen it still fails to contract). Oxygen is definitely concerned

Part of the tracheal system in an insect. The finer branches lead directly to the tissues.



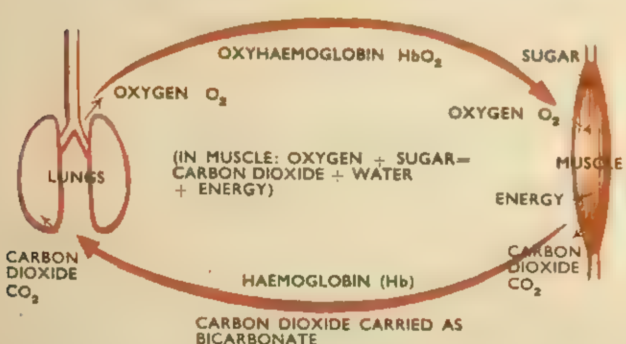


The permanganate crystals dissolve and the molecules diffuse throughout the water, colouring the whole of it. The molecules spread from a region of high concentration to one of low concentration, giving an even concentration throughout the water. This takes several weeks—care must be taken to avoid convection currents.



Air similarly spreads evenly throughout a space, but within the lung the oxygen passing in is constantly carried away by the blood stream so that it continues to diffuse through the wall of the alveoli.

A summary of the exchange of gases taking place in the lungs, the transport of oxygen away from them to the tissues, and the return of waste material from the tissues to the lungs.



with the supply of energy to the muscle, but not directly because a fresh muscle will contract for a time in an atmosphere of nitrogen. An active muscle produces large amounts of carbon dioxide, much more than a resting muscle. After repeated contractions the amount of sugar in the muscle is much lower and other simpler substances can be detected in its place. So in doing mechnical work a muscle uses up oxygen and sugar and produces carbon dioxide.

If some sugar is burned in air (i.e. oxidized) carbon dioxide and water are formed and energy (in the form of heat and light) is released. The end products of this are the same as for the processes going on in muscle which may be closely compared with the burning of a candle. In both cases a substance containing carbon, hydrogen and oxygen is broken down to carbon dioxide and water with the release of energy. In these respects burning is similar to *respiration*, the name given to the changes taking place in muscles and other living tissues in which energy is released. There are important differences, however. Firstly, the temperature at which burning takes place is far higher than the delicate machinery of the living cells could withstand; secondly, during burning the energy is released as heat and light and this is by no means always so in respiration; thirdly, burning by oxidation cannot take place in the absence of oxygen whereas energy can be released in muscles, although oxygen is needed for the process to continue.

Respiration may be summarised as follows:

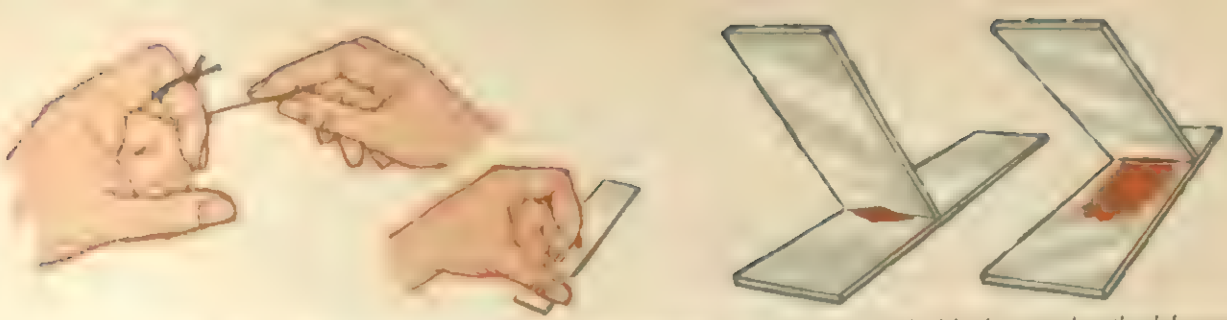
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

Although it is shown here as one reaction many chemical changes are needed within the cell, each controlled by an enzyme.

Breathing and the blood

The essential features of respiratory organs are: 1. a large, moist surface area, 2. very thin walls, and 3. a good blood supply. Whether the animal is on land or in water, the oxygen it requires must be in solution (dissolved in a liquid) before the animal can use it. (Similarly a plant cannot use gaseous oxygen; it must dissolve in the liquids within it.) The water flowing over the gills of a fish contains oxygen already in solution but in an animal with lungs the oxygen has to dissolve in a layer of slime (mucus) lining them before it can pass any further.

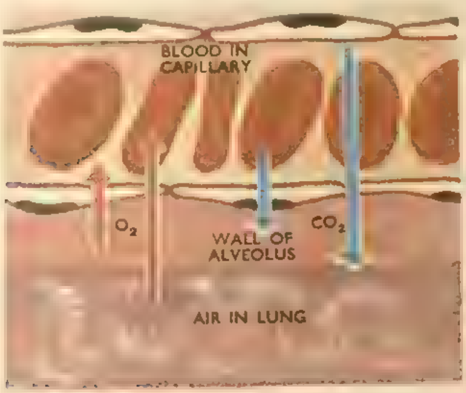
Why does oxygen pass from the lungs into the blood or from water into the gills of a fish and carbon dioxide in the opposite direction? If a few crystals of potassium permanganate are placed in a beaker of water they will dissolve, colouring part of

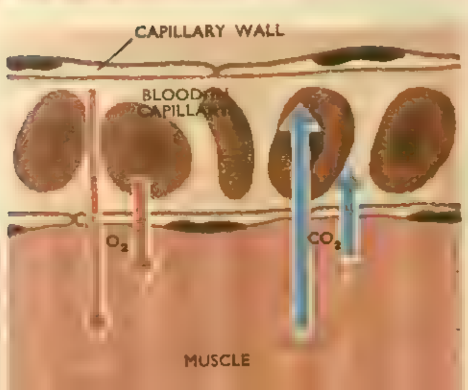


A drop of blood for making a smear may be obtained by pricking the finger just behind the cuticle. Blood is spread on the slide using another slide held at an angle. Movement of the slide spreads the blood by means of capillarity.

the solution. After a while, however, the whole solution will be coloured. What has happened? The molecules of potassium permanganate move about freely in the water in all directions so that eventually they will be equally dispersed throughout the water. This spreading—called diffusion—occurred from an area of high concentration to those of low concentration until the distribution was equal. The oxygen concentration in the lungs is much higher than that in the blood, and so oxygen will pass from the lungs into the blood by diffusion. But because blood which has used up its oxygen

(Above) Oxygen diffuses from the lungs through the wall of the alveoli into the blood capillaries. Carbon dioxide passes in the reverse direction. At the tissues (lower illustration) oxygen passes from the blood capillaries, where its concentration is high, to the tissues where the concentration is low. Carbon dioxide passes in the reverse direction. Blood which was bright red now reverts to the normal purple-red colour of haemoglobin.





is constantly being pumped through the lungs oxygen continues to pass from the lungs into the blood. Similarly blood arriving back at the lungs from the tissues is rich in carbon dioxide. The fresh air just breathed in contains little carbon dioxide. So carbon dioxide passes from the blood into the lungs ready to be breathed out.

Blood arriving at the tissues (e.g. muscles) from the lungs is rich in oxygen and poor in carbon dioxide. The tissues have less oxygen and more carbon dioxide so diffusion takes place—oxygen leaves the blood for the tissues and carbon dioxide passes from the tissues into the blood to be carried back to the lungs.

How is oxygen carried in blood?

The fact that oxygen is carried in blood in a particular way depends on the following experimental evidence. Study the evidence and answer the question.

Water in contact with air contains, in solution, about 1 part of oxygen to every 100 parts of water. Air contains about 20 parts of oxygen to every 100 parts of air. It is possible to drive the oxygen out of blood which has been in contact with air, by exposing the blood to low pressures or by chemical means. This oxygen can be measured. Human blood which has been exposed to air has been shown to contain 20 parts of oxygen to every 100 parts of blood.

If the red blood cells are removed from blood, and the remaining plasma is exposed to air, the oxygen content of the plasma is about 1 part per 100.

Deduce from this evidence how oxygen is carried by the blood.

The blood of vertebrates and some invertebrates, (e.g. the earthworm), contains a red pigment called *haemoglobin*. At high oxygen concentrations it combines readily with oxygen to form *oxyhaemoglobin* which is bright red in colour. Blood containing haemoglobin can carry far more oxygen than blood lacking a pigment. (Active tissues such as those of warm-blooded mammals could not work if the blood lacked haemoglobin—they would be starved of oxygen.) In Man the haemoglobin is contained in the red blood cells so most of the oxygen in the blood is carried in these cells. When it arrives at the tissues—which are low in oxygen—the oxyhaemoglobin gives up its oxygen, becoming the dull red haemoglobin again.

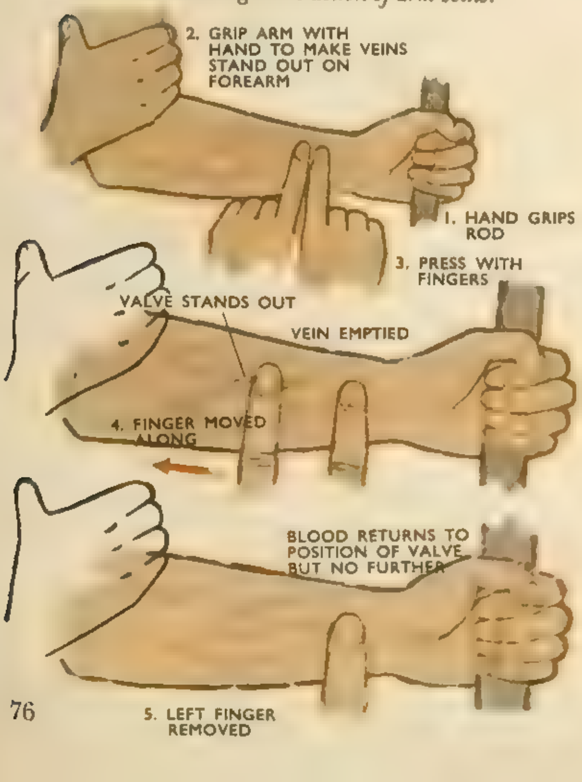
The Circulation

The human heart and circulation

UNTIL the beginning of the seventeenth century it was firmly believed that the blood ebbed and flowed away from and towards the heart. This was mainly because no connecting channels had been discovered between the arteries and veins. It could be seen that the arteries branched into smaller and smaller vessels as they penetrated the organs but, at that time, without the aid of a microscope the fine connecting vessels *(capillaries)* could not be seen. But William Harvey, even though he had no microscope with which he could observe capillaries, was firmly convinced as to 'the existence of channels through which the blood flows between the arteries and veins'. Marcello Malpighi (1628-1694) first noticed the capillaries a few years after Harvey's death in 1657, and thus proved Harvey to be correct.

By dissection, shrewd observation and experiment Harvey showed that the heart was a hollow, muscular sac which forced the blood into the arteries, thus giving rise to the pulse. He measured the heart's volume, the amount of blood it pumped at each beat and tied off various arteries and veins showing that the total blood volume was pumped by the heart in a very short time, yet none of the blood vessels were ever emptied of blood.

Demonstrating valve action of arm veins.



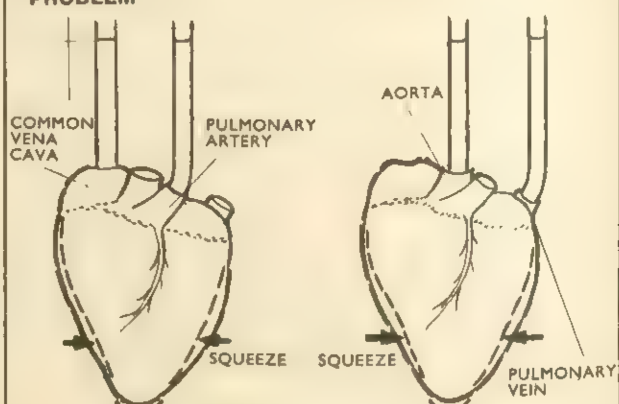
He also demonstrated the role of the valves in the veins of the arm, showing that they prevented the blood from flowing back towards the fingers.

While working normally we are hardly aware of the heart's rhythmic beat, but after strenuous exercise it beats so much more strongly that we may feel as though it is trying to burst its way out of the body. This is but one instance of the way in which the activities of some parts of the body are continually changing to cope with the varying demands of other parts. Just as the heartbeat varies so does the blood supply to different parts of the body. When we move, the supply to muscles is increased, more channels are opened up there to carry the increased supply in order that the tissues can receive greater quantities of fuel and the oxygen needed to burn it. At the same time the supply to the skin and gut may be cut down.

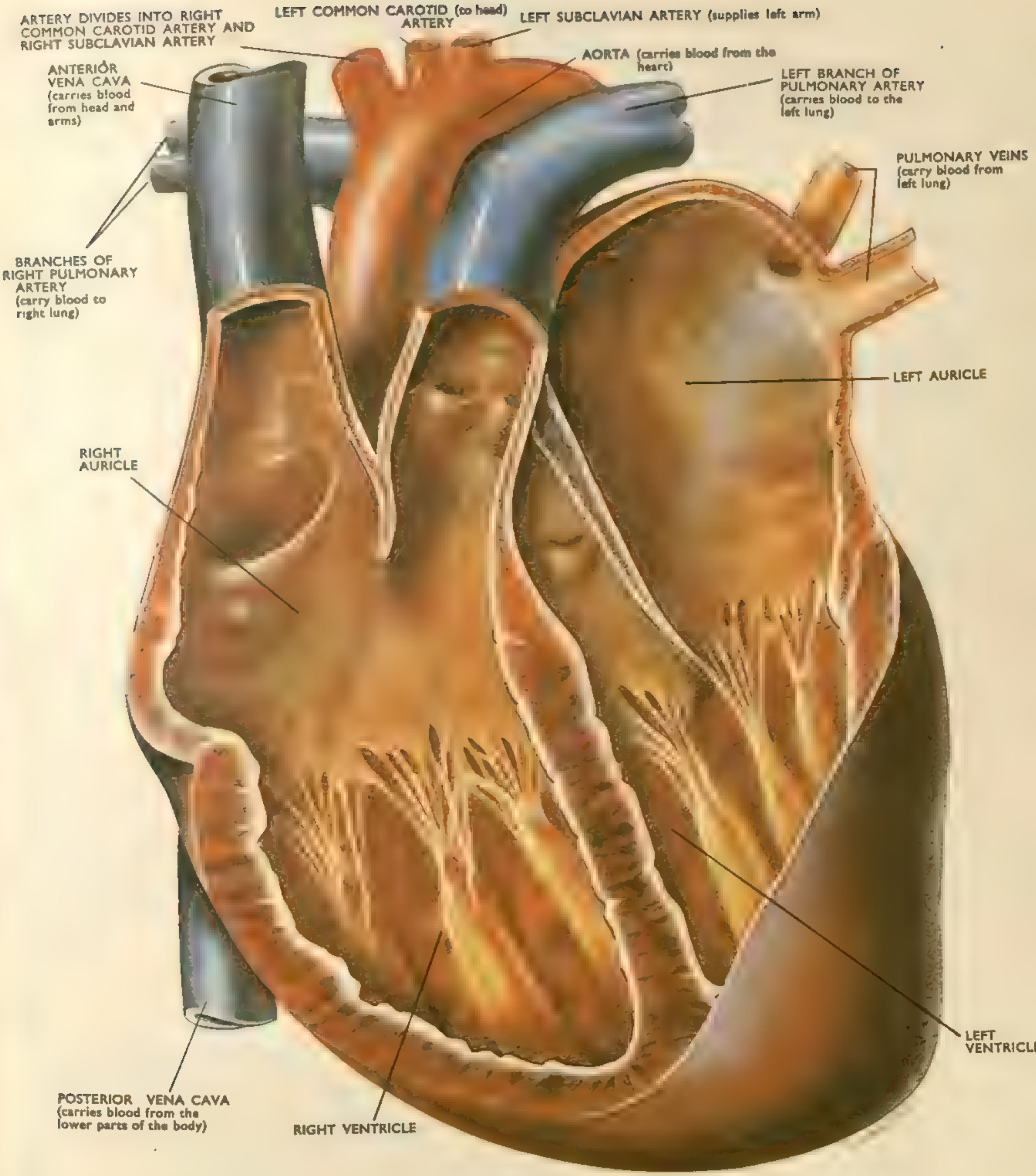
The heartbeat and its variations

a. Record the heart rate (everyone in the class seated) for all the people in your class. Record the rate in beats per minute.
   1. What is the slowest heart rate?
   2. What is the fastest?
   3. What is the average?
   4. Try to work out a way of illustrating the variation of the heart rate within the group.

PROBLEM



Into the common vena cava of a sheep's heart insert a foot-long piece of glass tubing and tie it in tightly. Insert a second piece of tubing into the pulmonary artery then fill the heart through the vena cava and pulmonary vein until several inches of water are visible in each tube. Squeeze the heart and note what happens to the level of water in each tube. Explain. Remove the tubes, insert one into the pulmonary vein and the other into the aorta. Again fill the heart with water, squeeze and see what happens to the water levels. Explain.



An enlarged view of the human heart from the front, cut away to show its structure

Is there any connection between heart rate and sex or heart rate and size?

b. Investigate the effect of physical activity, and recovery from physical activity, on the heart rate.

Step on and off a chair 30 times at a rate of about once every two seconds. Sit down. Measure the radial pulse rate for the first ¼ of a minute. Record this, then for the 3rd ¼ minute, the 5th ¼ minute, and so on.

Plot a graph of heartbeat against time from end of exercise. Suggest reasons for your results—what causes the heart to beat faster? In everyday language how does your heart know your muscles are doing more work? You will be able to see that some reasons are more likely than others. For example, it might be the movement of the muscles, but if the heart rate continues at a fast rate when you have sat down, then this cannot be a completely satisfactory explanation.

We know that most of the substances in the blood do not stay within the blood system. Oxygen, and the products of the digestion of food, pass out of the capillaries into the tissues and waste materials etc. pass in. When the muscles are working the extra fuel that they need (glucose) is released into the bloodstream by the liver. The kidneys extract waste matter from the blood so that its composition on entering and leaving that organ is changed. Not only are parts of the vessel system adjustable but also the fluid within them is continually having some materials added to it and others taken away.

Mammals and birds are the only warm-blooded animals. To maintain the high body temperature large quantities of fuel and oxygen are required by the tissues whose work produces large amounts of waste materials. These must be removed rapidly and fuel and oxygen supplied quickly if the tissues are to continue to function efficiently. Thus blood must be moved rapidly round the body. In man the heart beats approximately seventy times per minute and a complete circulation takes approximately twenty-five seconds. The blood is pumped to the tissues under a high pressure. This is the result of the *double circulation*, an arrangement by which blood poor in oxygen, returning to the heart from the tissues, is kept separate from blood rich in oxygen that has returned from the lungs and which is about to be pumped round the body again. Oxygenated blood, therefore, has to pass only through the capillary system to the tissues on its way round the body. In fishes, where the heart is not divided into two halves, deoxygenated blood is pumped to the gills for oxygenation and passes through a set of capillaries there before flowing to the tissues. Blood in fishes reaches the tissues at a fairly low pressure.

The human heart is a muscular, four-chambered sac situated underneath the breastbone and between the lungs. It is divided vertically into right and left halves and each half has two compartments. The top compartments are called *auricles* (or atria) and the lower ones *ventricles*. The latter have thick muscular walls by whose contraction blood is forced out of the heart to the lungs and to the body.

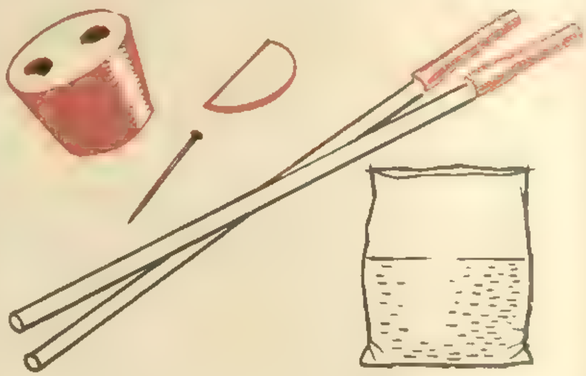
Practical problem on the action of valves

Given: a boiling tube, a cork with a hole in it, a plastic disc, and a pin, and a six inch length of glass tube with rubber tubing attached.

Devise an apparatus which demonstrates the action of a valve.

Given: a cork with two holes in it, a plastic disc and a pin, two lengths of glass tubing each with rubber tubing attached, and a small polythene bag half full of water.

Make a model ventricle.

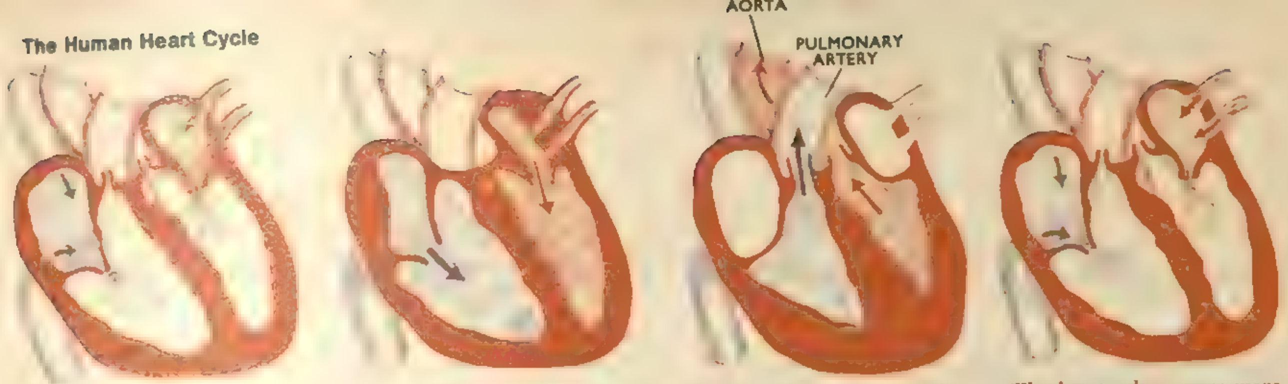


Blood from the head and body enters the *right auricle* through large veins. A valve is forced open allowing blood into the *right ventricle*. As the right ventricle contracts, the blood pressure rises shutting the valve and blood is forced out through a large vessel, the *pulmonary artery*, that has a right and a left branch. Each supplies a lung in which it splits into a branching mass of capillaries. The blood collects a new supply of oxygen in the lungs and returns to the heart through the *pulmonary veins* which enter the *left auricle*. A valve is forced open and blood flows into the *left ventricle*. As the left ventricle contracts the blood, now rich in oxygen, is forced out of the heart round the body. Both auricles contract more or less together, as do the two ventricles, so that blood is forced to the lungs and to the body at the same time, but at all times blood rich in oxygen (i.e. returning from the lungs) is separated from blood poor in oxygen (i.e. returning from the body).

It is possible to introduce small balloons on the end of tubes into the heart while it is still working. If the pressure in the part of the heart containing the balloon rises, the changes of pressure can be recorded outside the body. In this way graphs can be produced which tell us how the pressure is changing in, for example, the right auricle and ventricle.

Study the graph and answer the questions that follow.

The Human Heart Cycle



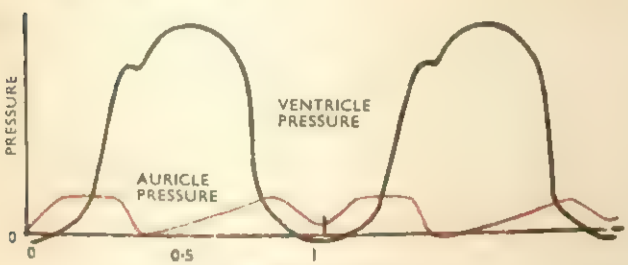
Between heartbeats (i.e. when the heart is relaxed) both auricles are filled with blood. A little may enter the ventricles.

As the auricles contract, the valve between each auricle and ventricle opens and the ventricles are filled with blood.

The ventricles contract, forcing blood out of the heart through the valves in the aorta and pulmonary artery.

The heart relaxes once more. The auricles fill with blood and the cycle is ready to start again.

HUMAN HEART CYCLE

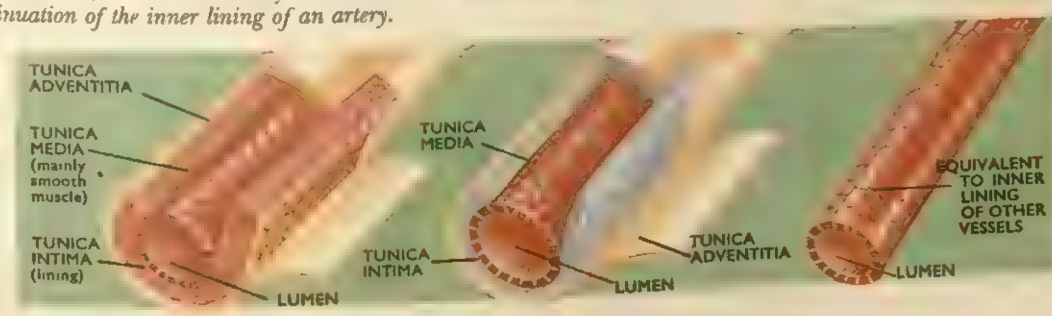


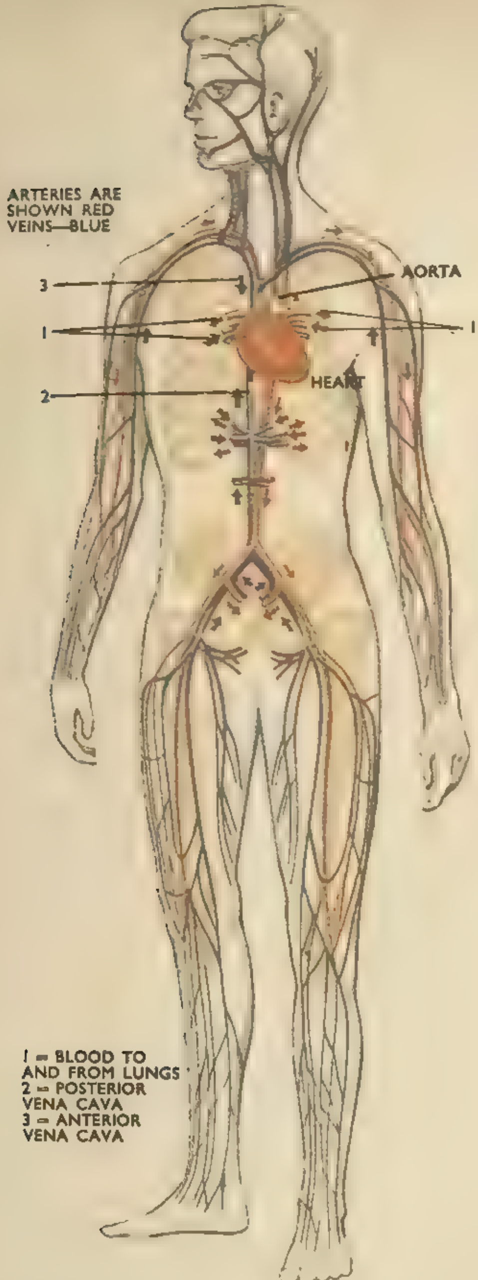
a. How many heartbeats are recorded here?
b. Which develop greater pressure, the auricles or ventricles?
c. Draw an x on the graph at the time when the valves between the auricle and ventricle will (a) open, (b) close.
d. Draw a line under the graph to indicate when the blood will flow *from* the auricles *into* the ventricles.

Vessels that carry blood away from the heart are called *arteries*. These branch into smaller vessels called *arterioles* which break up in the tissues into *capillaries*—channels whose walls are only one cell thick. Because the capillaries branch so many times in the tissues and because they have thin walls, substances in the blood are brought into close contact with the cells and materials can pass easily between them. The capillaries join up again to form *venules* which come together to form *veins* through which blood flows back to the heart. This blood is usually de-oxygenated, though in the case of the pulmonary veins the blood is rich in oxygen.

The pressure at which the heart forces blood through the arteries gets smaller and smaller as the arteries branch and their diameters decrease. It is only about one tenth of its original value by the time the blood emerges from the capillary network into the veins. This venous blood pressure is not sufficient to force blood back to the heart. How then does blood pass from the veins to the heart? The sucking action of the heart is partly responsible, but this too is not strong enough on its own. The veins themselves are able to contract and they help to force the blood into the heart. They have valves which prevent the blood from flowing away from the heart (the valves of the veins on the inside of the forearm can be seen as swellings by tying a bandage round the arm just above the elbow). Their walls are thin and not so muscular as those of arteries but the lumen or bore is greater. The contraction of the muscles between which veins

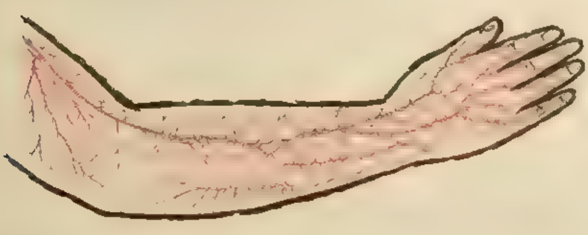
The walls of arteries and veins consist of three main layers. The lumen of an artery (left) is smaller than that of a vein of similar importance (centre) but the muscle layer is much thicker. (right) A capillary (highly magnified) has a wall only one cell thick. This is a continuation of the inner lining of an artery.





The blood system in Man showing the main vessels and the direction of blood flow.

X-ray of arteries of the arm injected with dye showing how they branch to supply all parts of the arm.



pass also massages the blood along towards the heart.

Though heart muscles beat of their own accord (i.e. without receiving nerve signals) the frequency of the beat is controlled by nerves. Two sets of nerve fibres supply the heart, one parasympathetic in the *vagus nerve*, the other sympathetic. Various factors such as emotion, the rate of breathing, temperature, exercise, the volume of blood flowing into the right auricle and out of the aorta and the quantities of oxygen and carbon dioxide in the blood can affect the heartbeat.

When it is necessary to introduce anything into the bloodstream, for example glucose solution or more blood, a tube is placed pointing towards the heart in a vein. Explain why a vein (and not an artery) is used, and why the tube is pointed towards the heart.

Circulation in other vertebrates

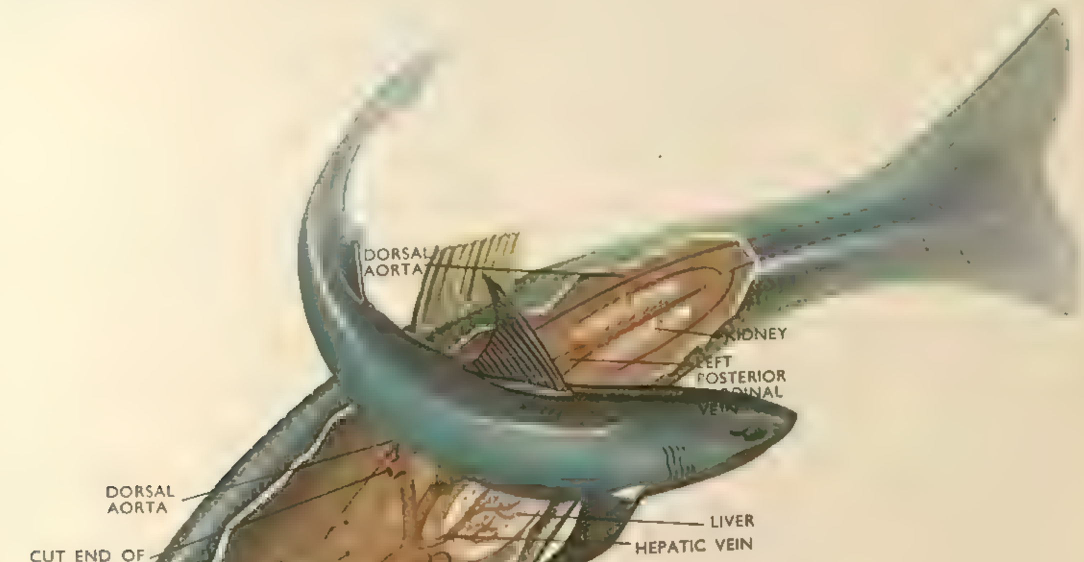
In its main features the blood system conforms to the same basic plan in all vertebrates. As the vertebrates have evolved from a fish-like ancestor, changes in the blood system have taken place, some associated with the great change from breathing oxygen dissolved in water to breathing oxygen in the air. This came about when the transition from dwelling in water to living on land occurred.

In gill-breathing vertebrates (e.g. fishes) blood is pumped forwards from the *heart* along the *ventral aorta* in the floor of the throat. A series of vessels pass upwards from the ventral aorta to the gills on either side of the throat. There they break up into a network of *capillaries* which provide a much increased surface area in contact with dissolved oxygen in the water. The capillaries rejoin to form vessels that pass upwards to join the *dorsal aorta*, along the hind part of which blood flows back to supply the body and which in its front part supplies the head. Branches from the dorsal aorta supply the various parts of the body—skin, limbs, kidneys, liver etc.

In the tissues the arteries break down into a system of capillaries. These are so fine and form such an elaborate branching network that most of the cells are near to, or actually in contact with, a capillary. The passage of food and oxygen to the tissues and of waste materials in the opposite direction can take place quickly. If these materials had to 'seep' (diffuse) over greater distances between larger (less divided) vessels the rate at which the tissues work would be very much slower. It is doubtful if they would receive sufficient food and oxygen, for diffusion is efficient only over very short distances. This is why gill plates and the walls of the alveoli are so thin.

The system of veins (venous system) bringing blood from the capillary system to the heart is complicated, but basically consists of the following sets of vessels: those that pass from the gut to the liver *(hepatic portal system)* and the *hepatic veins* from the liver to the main veins entering the heart; veins from the back (dorsal) part of the body, the head and limbs; veins draining the lower or ventral part of the body wall; and, in animals with lungs, the *pulmonary veins*.

The heart of a fish pumps only blood poor in oxygen forward to the gills to have the oxygen supply replenished—the heart is just a series of unseparated chambers. A fish has what is called a *single* circulation. But land vertebrates breathe air—the heart handles blood that is pumped to the lungs to be oxygenated and also blood that it has just received from the lungs. It is obviously desirable that blood poor in oxygen and blood that is rich in oxygen should be kept separate, otherwise the efforts of the lungs are largely wasted and the tissues receive blood containing a lower proportion of oxygen. Frogs and the like rely largely on their skin for obtaining oxygen so there is less necessity for preventing the mixing of blood in the single ventricle—there are two auricles, one receiving blood from the tissues including blood oxygenated at the skin, the other receiving oxygenated blood from the lungs. In reptiles the heart is almost completely divided into separate halves and in birds and mammals the division is complete—there is no mixing whatsoever between blood returning from the body and blood returning from the lungs. They have a *double* circulation—one going to and from the lungs, the other to and from the body. The tissues only receive blood rich in oxygen, therefore.



The blood system of a bony fish (hepatic portal system omitted).

Blood and other body fluids

There are about nine pints of blood in the human body. Blood consists of a liquid *plasma* in which

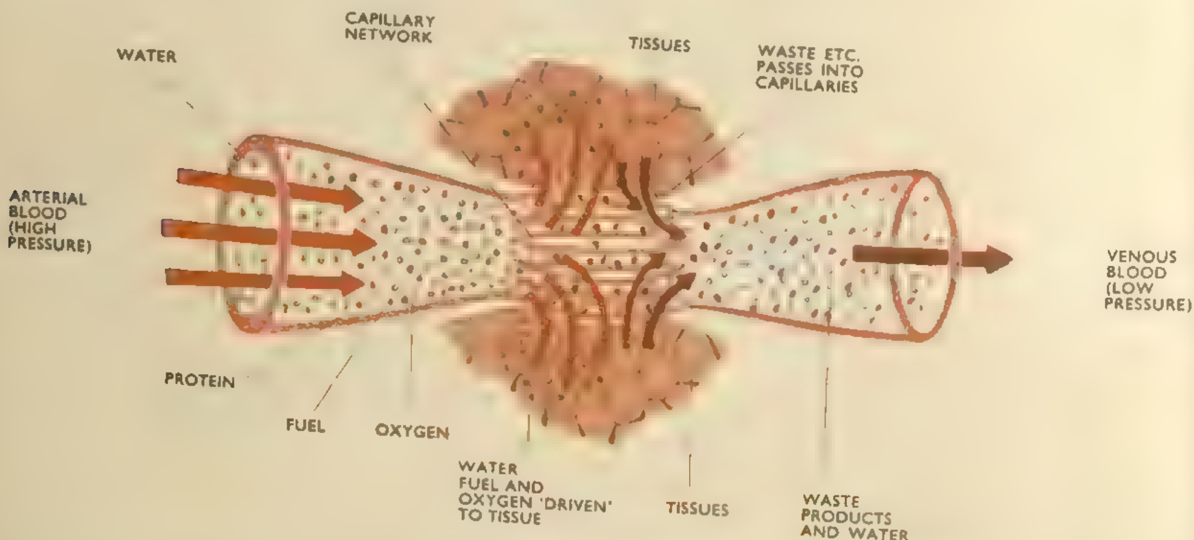
the cells or *corpuscles* float. The plasma contains appreciable amounts of salts and protein and smaller amounts of glucose, amino acids, fat, enzymes, hormones, antibodies and urea (the main waste substance formed by the breakdown of unwanted protein). The corpuscles are of two main kinds, red and white. The former contain most of the oxygen-carrying haemoglobin, which gives them their colour, and their main job is to carry oxygen in combination with haemoglobin (oxyhaemoglobin) from the lungs to the tissues. They also carry small amounts of carbon dioxide from the tissues to the lungs. In the male there are approximately 5 million red cells per cubic millimetre of blood (4,500,000 in the female). They have no nuclei—and so have a limited life of around three months. New red cells are constantly being manufactured in the marrow of the long bones and the ribs and reserves are stored in the spleen for release when required (e.g. during vigorous exercise).

The white cells are of several different kinds—there are about 5,000 per cubic millimetre of blood. *Phagocytes* have the important job of destroying and eating disease-causing bacteria. They are also the body's 'dustmen', eating dead bacteria and debris of all kinds including dead cells. Other white cells produce substances called *antibodies* that render harmless the poisons produced by disease-causing bacteria.

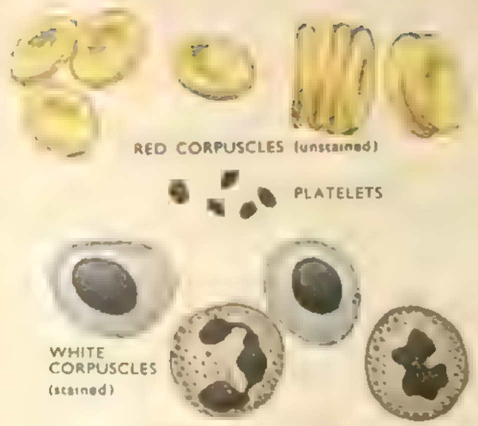
Other cell-like structures in the blood are the *platelets*, much smaller than the red or white cells. There are around a quarter of a million per cubic millimetre of blood. They play an essential part in blood clotting by which any breaches in the blood vessels are plugged.

The blood is pumped at a high pressure to the tissues—a pressure greater than that produced by the large molecules of blood proteins (the *blood osmotic pressure*). Water, salts, glucose and other substances with molecules small enough to pass through the capillary walls are driven *out* of the capillaries to the fluid around the tissues. The blood pressure due to the heartbeat drops as it passes further through the network of capillaries until it becomes less than the osmotic pressure. So water diffuses back into the capillaries. Waste materials are also returned; in this way the cells are nourished and relieved of waste substances. Substances with small molecules probably diffuse through the capillaries because of concentration differences between the blood and the tissue fluids.

The greater part of the plasma is water. Many of the activities of the blood are directly related to the properties of water. Because water gains and loses heat more slowly than any other substance the blood can transport heat from one part of the body to another. Also, since the body as a whole contains so much water, its temperature will not be subject to rapid ups and downs. So the conditions



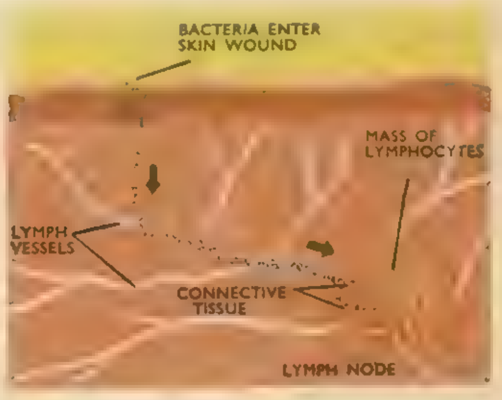
A diagram showing the circulation of fluid between the blood capillaries and the cells and spaces of the tissues. Water and dissolved substances other than proteins are driven out of the capillary at the arterial end because the pressure due to the heartbeat (hydrostatic pressure) is greater than the osmotic pressure. Waste materials, some salts and water pass into the capillary at its venous end because the osmotic pressure is greater than the hydrostatic pressure.



Human blood corpuscles (highly magnified).

under which the tissues work are very constant. More substances will dissolve in water than in any other solvent, so the blood can transport a host of chemicals from one part of the body to another.

Blood makes up only one tenth of the total fluid in the body. An adult man contains eighty to ninety pints of fluid. Some fluid bathes the tissue cells whilst the cells themselves also contain fluid. The fluid which bathes the cells contains all the substances that the cells require in order to work, and the waste substances produced by work are removed through it to the blood. It is in close contact with the blood system, receiving oxygen, fuel and other substances from the blood—the latter having obtained these from the lungs, digestive system and the glands. Waste materials pass in the reverse direction and are removed from the blood mainly by the lungs and kidneys. An alternative route by which substances are returned to the blood from the tissues is the *lymphatic system*. This special set of vessels returns fluid called *lymph* to the heart. Its vessels reach nearly all parts of the body. The lymph capillaries are blind tubes, slightly larger in diameter than blood capillaries. Molecules of all shapes and sizes, and even bacteria, can squeeze through the walls between cells. At intervals along the lymph channels are swellings—the *lymph nodes*. These are networks of connective tissue containing phagocytes and other white blood cells called *lymphocytes*. The lymph nodes are particularly important in times of infection when the phagocytes actively consume bacteria. They are the swollen 'glands' which enlarge in the armpits from an infected finger or in the neck from a septic tooth. Nodes near the lungs of city dwellers may become blackened by soot and other particles. Thus a major job of the lymphatic system is as a filter for bacteria and other foreign matter. The lymph vessels (*lacteals*) of the intestine have the important task of transporting fat away from the intestine. Chemically lymph is very similar to blood plasma but it has very little protein. It is moved along through the lymph vessels mainly as a result of body movements. Valves similar to those of veins prevent its backward flow.

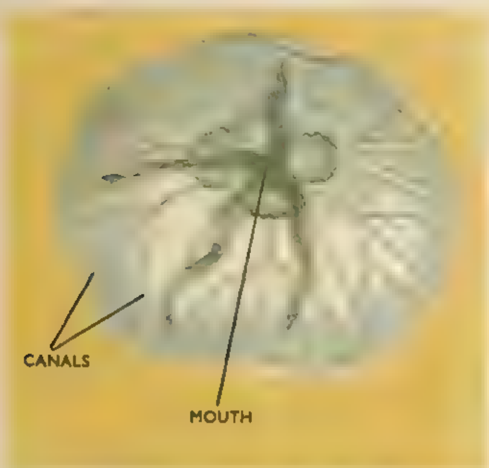


Bacteria may enter the tissues through a skin wound. They pass into the lymph vessels and are carried to the lymph nodes where many are destroyed by phagocytes. (below) Two drawings showing a phagocyte engulfing a bacterium; a process called phagocytosis.

Blood in invertebrates

The simplest animals have no need of a blood system. They are small enough or thin enough for oxygen and fuel to reach all parts in sufficient quantities by diffusion and for carbon dioxide and other waste to leave by the same means. A sea anemone which may be quite large overall has a very thin body wall and substances can reach the tissues from the hollow interior or directly from the surroundings. However, the jellyfish (*Aurelia*) has an elaborate system of canals rather like the spokes of an umbrella. Fluid carrying food is distributed to all parts in these canals.

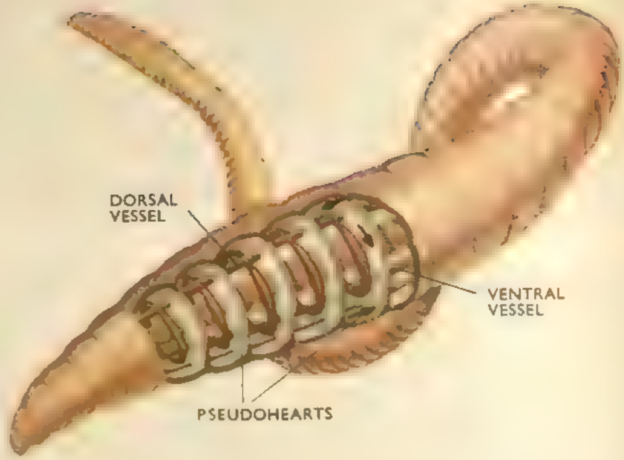
Other invertebrates—e.g. worms, insects, crustaceans—have a circulatory system of which one or more parts can contract to help circulate fluid. The speed with which substances are brought to the tissues and waste carried away is closely connected with the complexity of an animal, and also to how active it is. This is well illustrated by comparing active molluscs such as squids, which have a well-developed, efficient blood system, with the more



The common jellyfish, Aurelia, *showing the elaborate system of canals in which fluid carrying food is circulated to all parts.*

sluggish habits of bivalves and snails: the latter having a poorly developed blood system.

The circulation in many annelids (e.g. the earthworm) is like that of vertebrates in that capillaries are present between the vessels entering and leaving the tissues. Special cells (the *yellow cells*) move about in the fluid-filled space surrounding the gut, and take up waste substances. The blood contains a red

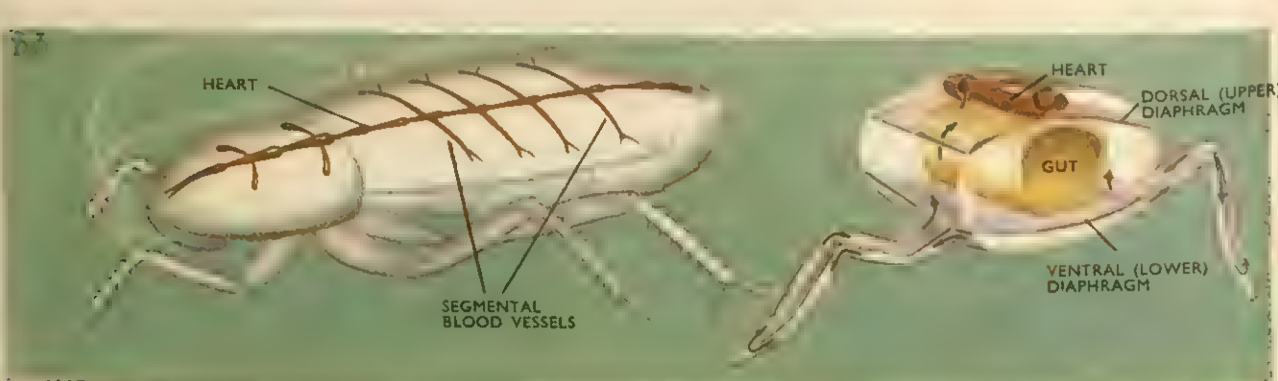


Blood system of an earthworm at the front end showing the 'hearts'.

pigment, haemoglobin, as does vertebrate blood, but it is carried in solution in the blood and not in the cells.

The blood system of insects is not well developed. The blood fills the body cavity and the internal organs are freely bathed in it. It penetrates the limbs and the wing vein cavities, but it is not important for carrying oxygen although it contains dissolved oxygen. The finest branches of the tracheal systems are close to the cells of the tissues so that oxygen has only a short distance to travel by diffusion. Very few insects possess a respiratory pigment. In fact the blood is more important as a water reservoir and also as a temporary food store. The blood of some insects (e.g. bees) is very rich in sugar. The main vessel of the blood system is the heart, a long tube lying above the gut. The heart contracts to move the blood around.

The heart and main vessels of a cockroach. (right) A block diagram of a body segment showing the position of the heart and diaphragms (sheets of tissue). The arrows indicate the direction of the blood flow.

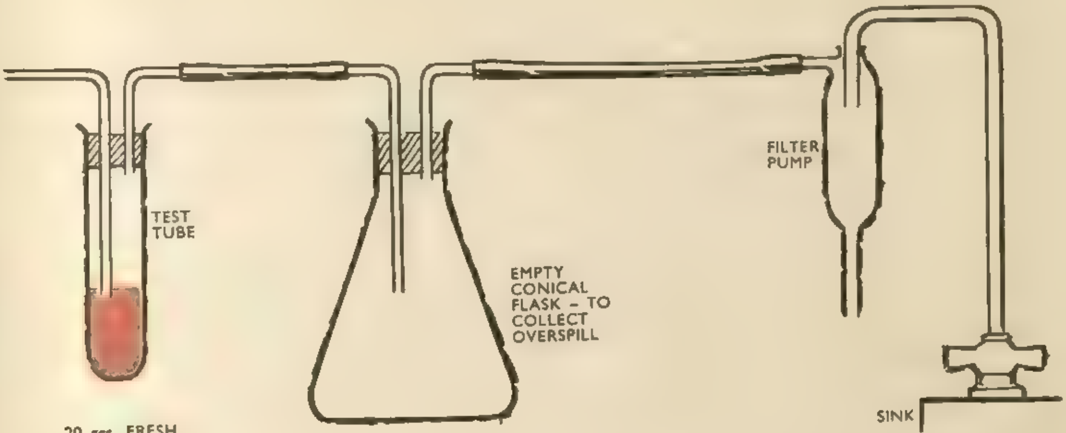


PRACTICAL PROBLEM

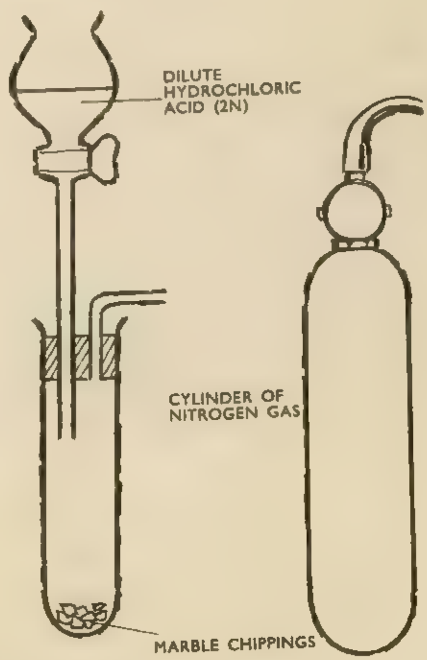
Body Fluids

Blood leaving the left ventricle is described as scarlet and blood entering the right ventricle as dull red in colour. The following experiment helps us to decide what causes the change of colour. Is it because the blood contains more or less carbon dioxide or is it because it contains more or less oxygen?

Blood for this experiment should be obtained from a slaughter house When the fresh blood is collected sodium citrate (6 gms per litre of blood) must be added to prevent clotting.
Put 20 mls. of blood into two clean boiling tubes.
Set up the apparatus as illustrated below.



APPARATUS (B)



Stages in experiment

(A) First blood sample

1. Turn filter pump on and draw air through blood for 2 minutes.
2. Disconnect first blood sample and keep this tube for comparison.

(B) Second blood sample

3. Repeat 1 (above) with second tube but do not disconnect.
4. Compare colours of blood sample against a white background.
5. Attach apparatus (B) to left-hand end tube.
6. Mix, little by little, the acid and marble chips. Filter pump still on.
7. After 2 minutes again compare colours of blood samples.
8. Disconnect apparatus (B). Draw air through for 2 minutes (as in 1 above).
9. Again compare colours.
10. Attach nitrogen bottle. Turn on *carefully* and repeat observations 7 to 9.

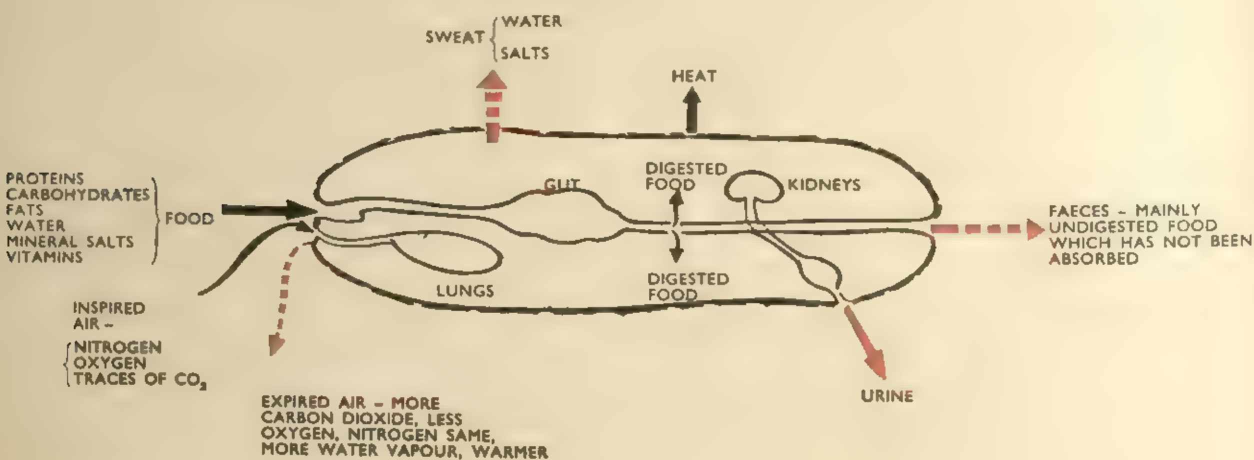
In this experiment two lots of blood are compared four times, in stages 4,7,9 and after stage 10. Each time the colours may be the same or different. Explain exactly what you learn from each comparison.

F

Excretion

Excretion – its purpose

Living organisms take substances into their bodies and give out substances Some substances pass through the body unchanged However, other substances which come out of the body are not the same as those which the body absorbed. In other cases the body gives out more of a substance than it absorbs.



Often by identifying the substances absorbed, or given out, by animals and plants we can get important clues about the chemical changes going on inside an organism.

Our study of respiration was a good example of this. Oxygen enters the body, carbon dioxide and energy leave the body, and carbon compounds enter in the food. All these facts were important clues to the chemical changes which are called respiration. The carbon dioxide comes from sugar molecules which are broken down with the release of energy

The removal of waste substances produced by the chemical changes going on in the body is called *excretion*.

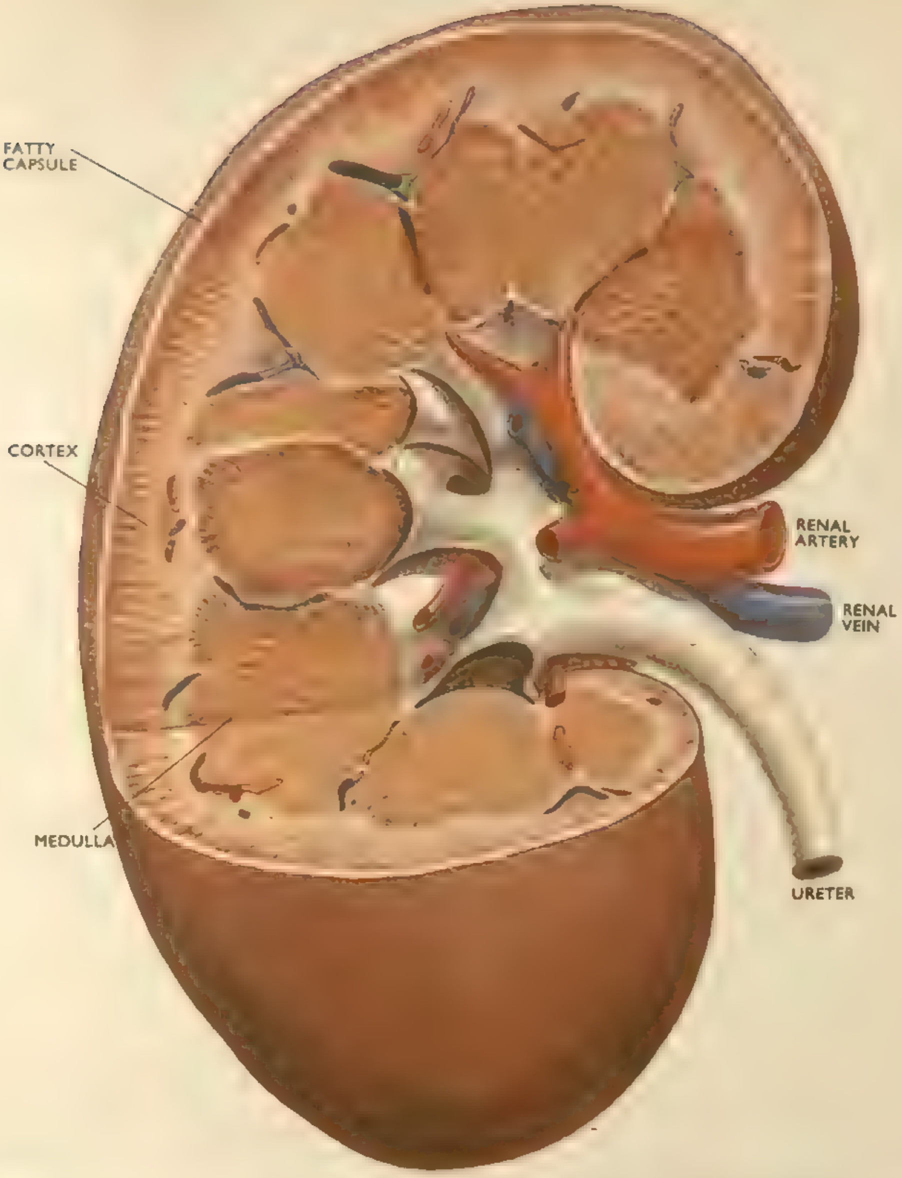
A problem

Some of the facts known from the analysis of urine of mammals are given below.

a. A substance called urea is invariably present in urine.
b. Urea contains the elements carbon, hydrogen, oxygen, and nitrogen.
c. The weight of urea per 100 ccs. of urine increases as the percentage of protein in the diet increases.
d. Proteins contain the elements carbon, hydrogen, nitrogen, and oxygen.
e. Carbohydrates and fats contain the elements carbon, oxygen, and hydrogen.
f. The percentage of nitrogen in inspired and expired air is the same.

What do these facts suggest?

Unless a fire is regularly raked to remove ash and to maintain an adequate supply of air it will eventually go out. The waste materials (ash) produced by the burning of the fuel choke up the fire and prevent it from burning. Living cells burn fuel to produce the energy needed for muscle action, replacement of damaged or worn-out tissues and the building of new tissues. This produces waste substances, some of which (e.g. lactic acid) can be broken down further to yield more energy, but others have to be removed from the body in order that the living processes can continue. If waste substances are allowed to accumulate they produce a number of harmful effects and eventually the organism dies.



A human kidney enlarged and cut away to show its structure (note that the colours of blood vessels are exaggerated for clarity).

Excretion in Man

The removal of waste substances from the body, mainly by the kidneys, is called *excretion*. In man, other forms of excretion include the removal of carbon dioxide from the lungs when we breathe out, sweating, and the growth of hair and nails. True excretion, however, should be restricted to the breakdown of wastes and their elimination by the kidneys in the urine.

The kidney as an organ of excretion

Urine is stored in the bladder which is connected by tubes to the kidneys.

Each kidney has three main tubes, entering or leaving it: the renal artery, which carries blood into the kidney, the renal vein, which carries blood out of the kidney, and the ureter, which carries urine from the kidney to the bladder.

Blood contains blood cells, soluble protein, glucose and 0·03% urea, among other things.

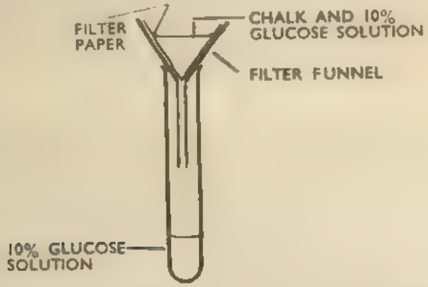
Urine from a healthy person never contains blood cells, protein, or, under normal circumstances, glucose, but contains about 2% of urea.

Damage to kidneys by disease may result in protein, glucose, or even blood entering the urine.

Answer the following questions from the evidence given above.

a. What is urine made from, and where is it made?

b. Which facts suggest that the kidney is a filter?
c. Which facts suggest that the kidney is not a simple filter, merely separating soluble from insoluble substances?
d. Which fact cannot be explained using the simple idea of the kidney as a filter, even a filter with very fine 'pores'?
Hint for part d (diagram below).



The work of the kidneys is much more than just the removal of waste, however. They play a part in controlling the quantity of water lost to the outside world—most important in land animals; they help regulate the pH (i.e. level of acidity or alkalinity) of the blood and the general balance of salts in the blood, and hence in the body fluid as a whole; and lastly they conserve essential substances such as glucose and amino acids.

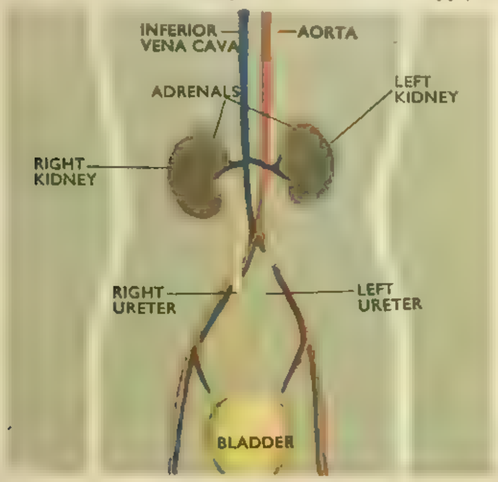
When the kidneys fail to function efficiently it is sometimes possible for doctors to employ an artificial kidney which temporarily takes over the work of the patient's kidney and purifies his blood.

In Man, the kidneys are paired, bean-shaped organs, one on each side of the backbone, lying under the gut in the 'small-of-the-back'.

A lengthwise section through a kidney shows two main zones; an outer *cortex* and an inner *medulla*. The whole is encased in a protective, fatty *capsule*.

Within the cortex and medulla are masses of tubules. They make up the bulk of the kidney tissue

The human excretory system and its blood supply.



and join up with larger *collecting tubes* that eventually form the main urine-carrying duct or *ureter*. This channels urine from the kidney to the *bladder*. Each kidney tubule has a rich blood supply; the renal artery and renal vein (together with the ureter) are prominent vessels entering or leaving the kidney.

The blind end of each kidney tubule lies in the cortex and may be likened to a champagne glass, the walls and stem of which are hollow and one cell thick. The 'bowl' of the tubule is called the *Bowman's capsule*. It surrounds an elaborate knot of blood capillaries—tiny branches of the renal artery—called the *glomerulus*. Each Bowman's capsule and glomerulus together form the *Malpighian body*—there are at least a million such structures in a single human kidney!

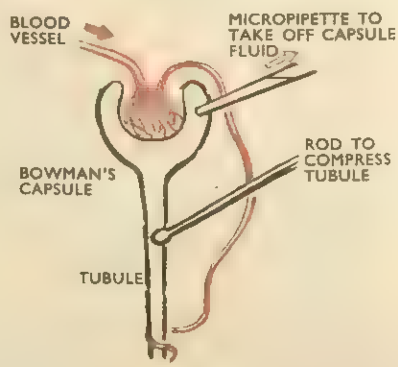
The hollow stem of the champagne glass is the upper part of the kidney tubule. This descends into the medulla where it narrows before turning upwards and ascending back into the cortex—increasing in diameter again. The thin portion of the tubule is known as the *loop of Henle* and is primarily concerned with the absorption of water. The ascending limb of the tubule joins a collecting duct which joins with others before eventually discharging its urine into the ureter.

The internal structure of the kidney and the function of the 'filters'.

The internal structure of the kidney has been worked out by section cutting and injection techniques, in the same way as you can do by following the instructions on page 90. The kidney is made up of structures which look like filters. A simplified version of a kidney 'filter' is given below.
See also a rather more sophisticated version opposite. . . .

It is possible to place a microscopically fine glass tube in the space between the walls of the 'cup' (in the kidneys of a toad which has fewer and larger 'filters'), and draw off fluid called filtrate.

A list of some of the substances found in blood, filtrate, and in urine are given in the table above right.



BLOOD PLASMA	FILTRATE	URINE
Proteins	No Protein	No Protein
Glucose	Same concentration of glucose as plasma	No glucose
Urea	Same concentration urea as plasma	60 times more concentrated
Ammonia	Same as plasma	400 times more concentrated

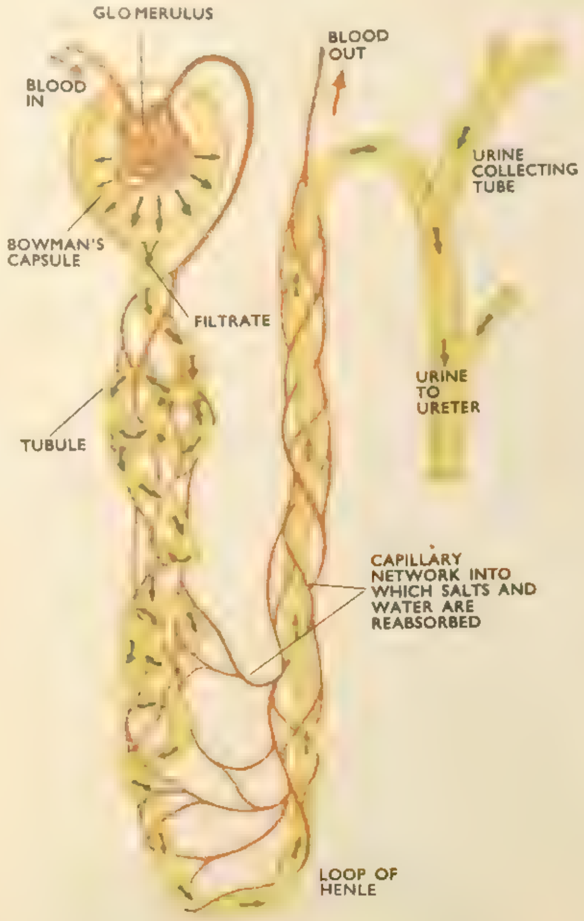
From this evidence try to work out what happens,
a. In the 'cup',
b. In the tube leading from the 'cup'.

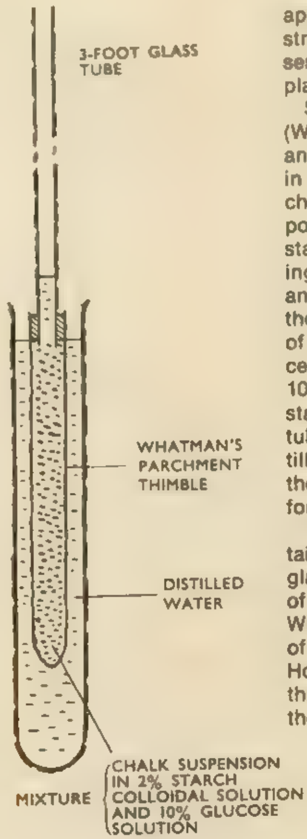
In effect each Bowman's capsule is a tiny filter. Blood containing waste substances, proteins, sugars etc. is forced to the kidneys by the pumping action of the heart. Under pressure, a solution is driven out of the capillaries of the glomerulus through the walls of the capsule into its hollow interior. (Materials are supplied to the tissues in a similar way.) The solution in the capsule (*filtrate*) is blood plasma minus the large (colloidal) molecules. These are too big to pass through the capillary wall.

From the capsule the fluid passes along the tubule. Many of the substances in it are absorbed through the tubule wall into the blood capillaries that envelop this, so that it gradually becomes more concentrated as *urine*. Organic molecules, such as some amino acids and glucose, some salts and water are absorbed in the first part of the tubule, whilst more water and salts are absorbed in the second part. Certain poisonous substances that have been rendered harmless are released into the urine by the tubules, together with potassium and hydrogen.

The normal daily output of urine is between two and a half to three pints, yet it is calculated that a total of nearly three hundred pints of fluid is filtered by the kidneys during that time. They not only reabsorb a vast volume each day but they also

A diagram of a single kidney tubule. Arrows show the direction of blood flow and the flow of urine.





PROBLEM

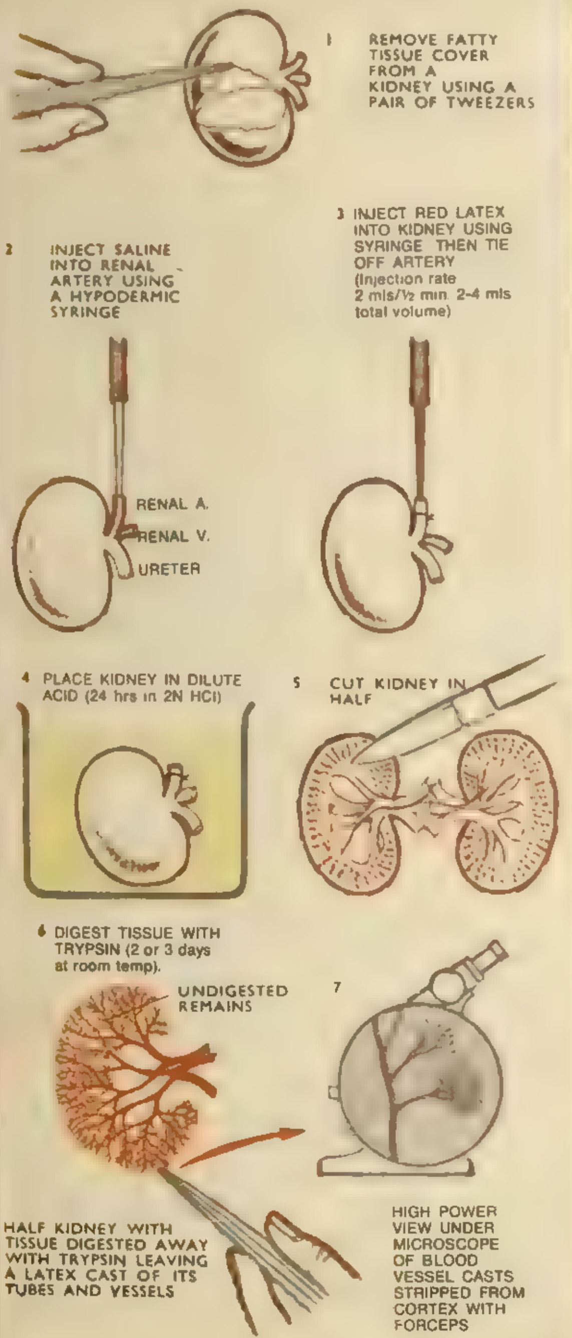
It is possible to set up an apparatus which demonstrates some of the processes which seem to be taking place in the kidney.

Set up a parchment tube (Whatman's supply these) and, having wetted it, place in the tube a mixture of chalk (insoluble), corresponding to blood cells, starch 'solution', representing the colloids of the blood, and glucose representing the truly soluble substances of the blood. The final concentration should be about 10% glucose and about 2% starch. Place the parchment tube in a boiling tube of distilled water. After a day test the water in the boiling tube for starch and glucose.

Wire a rubber bung containing a three-foot length of glass tubing to the open end of the parchment thimble. What happens to the level of the solution in the tube? How can you account for this? Is there a problem for the kidneys here?

MATERIALS REQUIRED

1 Red latex solution, and possibly a little ammonium hydroxide for thinning 2 Hypodermic syringe 2 to 4 ml capacity, with needle removed (Cheap disposable syringes can now be obtained free from benevolent medical practitioners.) 3 Three-inch length of cycle valve tubing. 4. Three-inch length of glass tube of suitably small diameter, somewhat drawn out. 5. A fresh lamb's kidney from a butcher 6 Cotton thread 7 2 per cent trypsin solution buffered to pH 9 or one drop 2N NaOH to 25-ml solution 8. 2N HCl



A section of kidney tissue (highly magnified) in which the arteries have been injected with dye showing clearly the knots of capillaries (glomeruli).

regulate its content so that the correct levels of essential substances are maintained in the body fluids.

The function of the various parts of the tubule has been analysed by inserting tiny pipettes into them and withdrawing small quantities of the fluid. Differences in the concentrations of substances in the fluid in different parts are strong evidence as to the function of a particular part. The content of the urine varies considerably with the type of diet that a person eats, however. For example, the nitrogen content of the urine is much higher in someone taking a protein-rich diet than in another who is eating starch-rich food, mainly due to the increased production of urea.

Excretion in other animals

There is a close link between excretion and the control of water loss from an animal. An animal that lives on land has to face the problem of finding and retaining sufficient water. It cannot afford to lose large quantities of dilute urine. On the other hand animals that live in fresh water have the opposite problem, for the strength of their body fluids is greater than that of the water in which they live. They can afford to lose large quantities of water in their urine.

The main nitrogen-containing waste substance that must be removed from an animal's body is ammonia. This is formed mainly when organic food materials containing nitrogen (proteins and amino acids) surplus to the body's requirements are used as fuel and broken down, releasing energy. Ammonia is a very poisonous substance and must be removed rapidly or converted into a less harmful

A simple animal, such as Amoeba, *which lives in fresh water has protoplasm containing more salts than the water in which it lives. It must remove surplus water to avoid swelling and eventually bursting.*

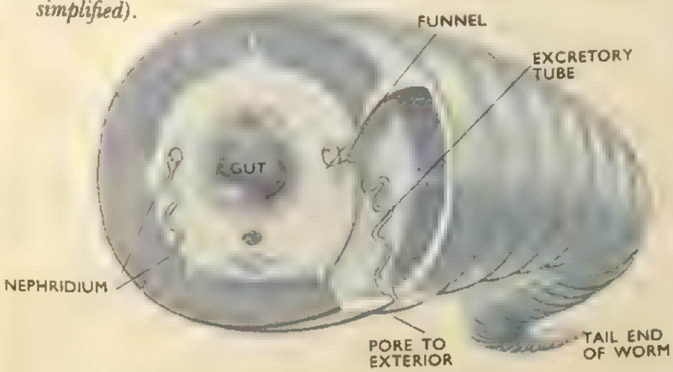
substance, such as urea.

In many simple animals that live in water, ammonia diffuses out of the body in solution (ammonia dissolves readily in water). Its removal in this way is rapid and efficient and protozoans and coelenterates (e.g. *Hydra*) have no need of special organs of excretion. The earthworm and other ringed worms have *nephridia* (singular: nephridium) of which there are one pair to each segment. These remove waste substances and also regulate the content of the body fluids. In the earthworm the intestine is covered with yellow cells that extract nitrogen-containing waste from the blood. When they are full of waste they break up and float in the body fluid, the finest particles being carried to the exterior through the nephridia.

Insects conserve water by incorporating *nitrogen* in their hard outer shell (cuticle) and they excrete mainly uric acid in their excretory organs. The cuticle is waterproof and so helps to restrict water loss.

Paired kidneys are the major organs of excretion in vertebrates, the basic pattern and action being similar to that described for Man. But because vertebrate animals live in such varied situations the

The position of the excretory organs of an earthworm (nephridia simplified).



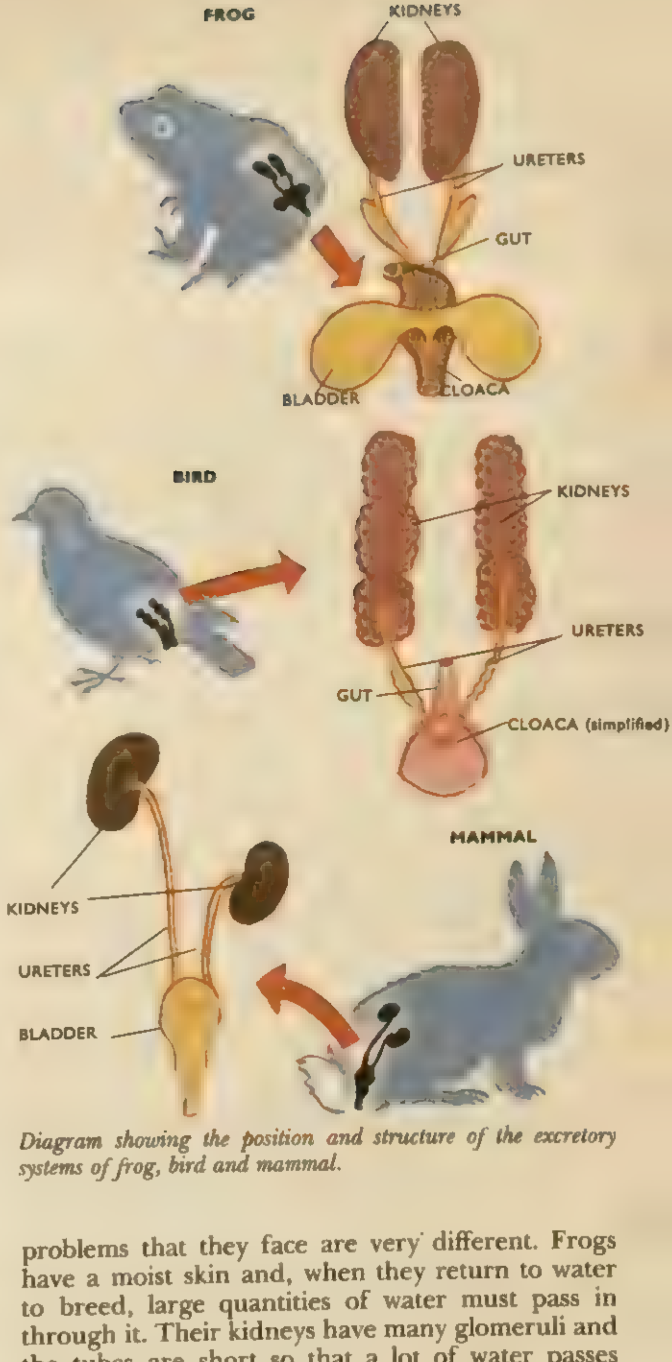
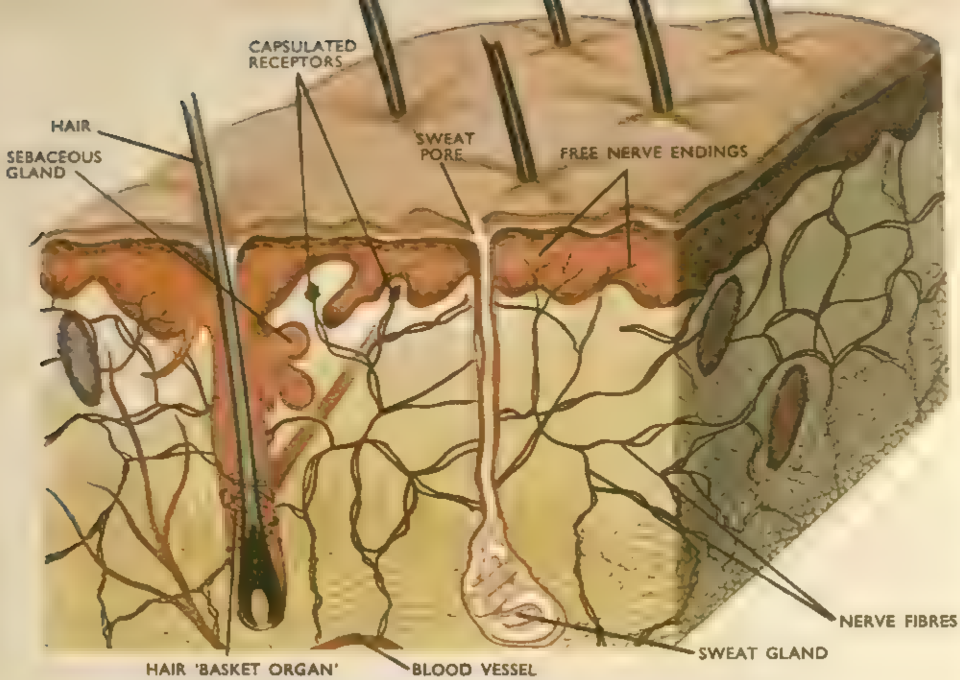


Diagram showing the position and structure of the excretory systems of frog, bird and mammal.

problems that they face are very different. Frogs have a moist skin and, when they return to water to breed, large quantities of water must pass in through it. Their kidneys have many glomeruli and the tubes are short so that a lot of water passes from the blood whilst little is absorbed. When on land some water is reabsorbed from the bladder. Frog tadpoles, which live in water, excrete ammonia whilst the adults get rid of urea.

Both birds and mammals have a water reabsorbing loop in the middle of the length of the kidney tubule so that a concentrated urine is produced. Birds excrete uric acid, an almost insoluble substance, so that water loss is reduced to a minimum.



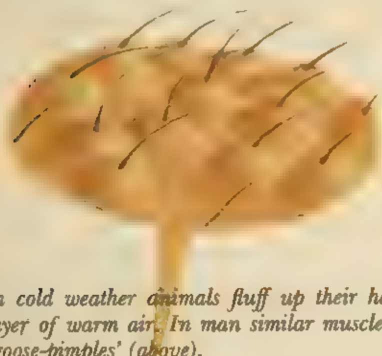
A block of human skin (enlarged) showing its main structures.

The Skin

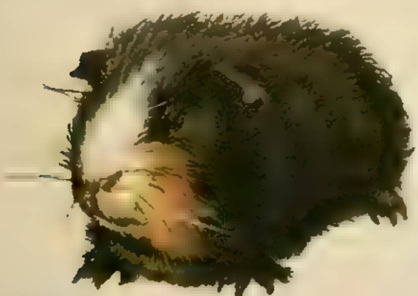
A fully-grown human being may have up to twenty square feet of skin. It is an essential organ performing a number of vital jobs; it protects the body against the entry of germs and against mechanical injury by acting as a cushion; its waterproof qualities prevent excessive water loss; it helps to control temperature and by sweating also helps with excretion and the regulation of water loss; it is richly supplied with sense organs that are sensitive to touch, pain, pressure and temperature and provide the brain with information about the surroundings.

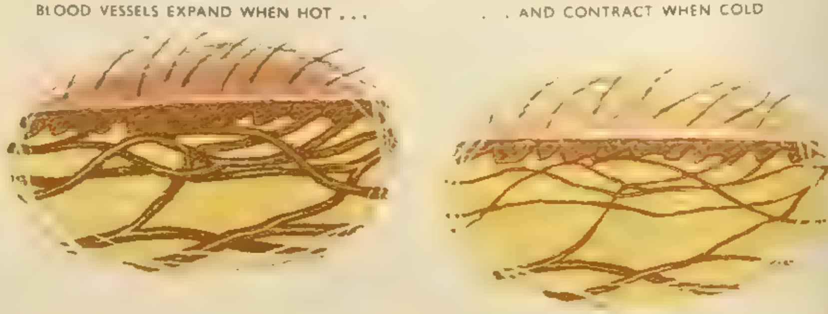
There are two distinct regions, the outer *epidermis* and an inner *dermis*. The innermost layer of the epidermis is the *Malpighian layer*. Its cells are living and divide frequently. They contain pigment which gives the skin its colour. As the cells divide the outer ones are pushed to the surface and gradually die, losing their protoplasm and ending up as horny scales. On some parts of the body they build up forming thick pads—as on the soles of the feet.

Underneath the Malpighian layer is the dermis. It is composed largely of connective tissue and, unlike the epidermis, contains many nerve fibres and blood vessels. Elastic fibres give skin its flexibility but, in old age, it loses this property and wrinkles develop. The upper layer of the dermis is irregular and the pattern is followed faithfully by the epidermis, this is why the fingerprint pattern reappears if the outer skin is damaged.



In cold weather animals fluff up their hair to trap a greater layer of warm air. In man similar muscles throw the skin into 'goose-pimples' (above).





Man, like other mammals and birds, is warm-blooded. His temperature is fairly constant at 98°F. The skin plays an important part in keeping this temperature constant. If, for any reason such as vigorous exercise or fever, the body temperature rises the temperature of the blood reaching the brain is raised. Nerve impulses are then sent to the blood vessels and muscles of the skin. The vessels widen and carry more blood close to the skin so that heat is lost to the air. The increased blood flow produces the flushed appearance. When the body temperature falls the chemical reactions in the body are usually speeded up to produce more heat. Shivering often occurs—a subconscious act that, through muscle action, produces warmth. 'Goose-pimples' may also appear, produced by the contraction of the tiny muscles attached to each hair. Other mammals fluff up their fur by similar means, so trapping a layer of air around their bodies which reduces heat loss. The blood vessels of the skin narrow when the temperature falls and less heat is lost to the air—at such times the skin appears pale, in contrast to the flushed appearance of fever. Sweating is another temperature controlling mechanism. It is the evaporation from the skin surface of water containing salts released by tiny coiled glands in the dermis—the *sweat glands*. Each gland is a tiny structure opening at the surface but there are so many scattered over the skin that the total cooling effect is considerable. Sweating is controlled by nerves and in cold weather the rate is reduced. In a humid atmosphere or when taking violent exercise, sweat may be unable to evaporate fast enough so that beads of perspiration accumulate on the skin.

Sweating is also an important means of controlling water content, the extent of which may be judged by the more frequent visits to the toilet in cold weather when the body sweats very little. But sweating does lose valuable salt (sodium chloride) too—this is why a miner is advised to drink beer rather than water after working.

Hair is produced by the epidermis. Each hair grows from a tiny pit or *follicle* of epidermal tissue which is sunk into the dermis. The base of each follicle is rather like an upturned wine glass the bowl of which contains the *papilla*, a structure richly supplied with blood and which feeds the hair. Cells at the base of the follicle divide repeatedly forming a growing string of cells—the hair. The older cells die so that a hair is not living. The colour is produced by pigments. Greying hair is due to trapped air bubbles in the hair cells. The hair is oiled by a gland in the hair socket—the *sebaceous gland*. Hairs have tiny nerves wrapped around their lower ends and are very sensitive to touch.

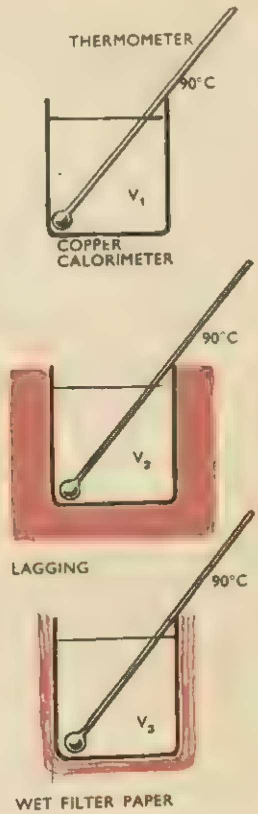
PRACTICAL PROBLEMS

Heat loss from hot bodies

1. Set up three copper calorimeters, of equal size, containing equal volumes of water, at the same temperature, at the same position in the laboratory and plot cooling curves* Treat each can as follows:

   Can no. 1 leave unlagged,
   no. 2 lag with some air-holding material,
   no. 3 cover with wet filter paper at the same temperature as the contained water.

   The water added to the calorimeters should be boiling and will give an effective initial temperature of about 90°C.



What information does this experiment provide which is useful in working out the action of the skin in temperature control?

2. Given 3 inch wide polythene (waterproof) bands and 5 cm squares of filter paper and a chemical balance how could you, (a) Find the weight of sweat produced per square metre on different parts of the body surface, (b) Find how this varies with physical activity.

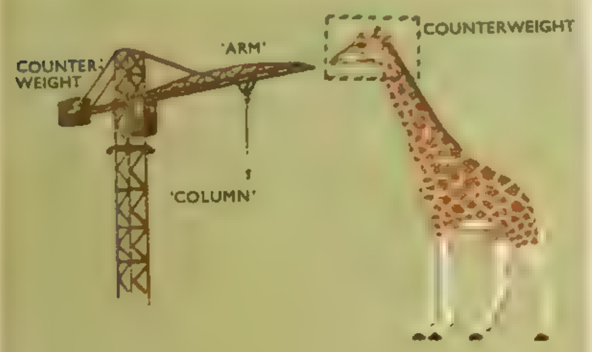
* Take temperature every 30 seconds.

The Skeleton and Musculature

The role of the skeleton

Most animals have a skeletón. In backboneless or invertebrate animals (insects, crabs, snails etc.) it is usually a hard outer- or *exoskeleton*. In backboned or vertebrate animals (fishes, birds, mammals etc.) the skeleton is a hard inner- or *endoskeleton*. Movement in all but the very simple animals, such as *Amoeba*, is carried out by muscles which contract and relax. In animals with a hard, articulated skeleton (e.g. insects, vertebrates) the muscles concerned with movement are attached to the skeleton on either side of a joint. In other animals (e.g. earthworm) muscles are often arranged in cylinders and work against a fluid inside the cylinder.

In addition, if an animal is at all bulky, it requires some framework or rigid system of girders on which the soft parts of the body can be hung to prevent the whole mass from collapsing into a heap. Animals which live in water only need comparatively light skeletons, for water is dense enough to provide a large amount of support. A whale has a comparatively light skeleton and when stranded on land such is its weight that the lungs are compressed and the whale being unable to breathe will suffocate unless refloated quickly by the tide.



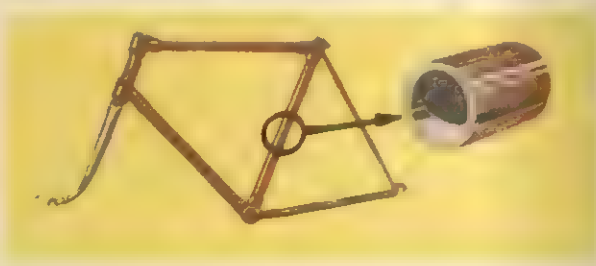
Without the counterweight there would be considerable bending stress in the column of the crane. By counter-balancing the arm all the weight is applied vertically to the column, allowing it to be more slender. In a similar way the weight of the giraffe's body is counter-balanced over the front limbs by the head and the neck, so allowing the limbs to be fairly slender.

Engineers could use shape A for a girder but in fact use B which is just as strong and consumes less material.

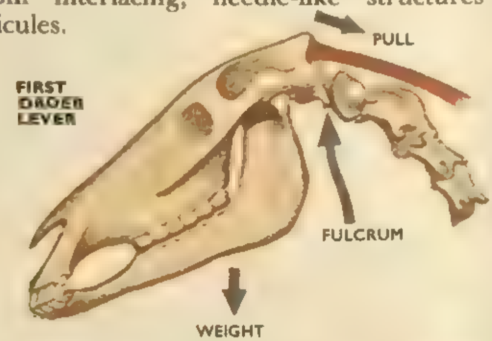
Since many parts of the skeleton are made of some tough, rigid material, it can also protect vital organs against damage: the braincase of the skull, the backbone surrounding the spinal cord, and the ribs and breastbone round the heart and lungs are examples of this in the human body.

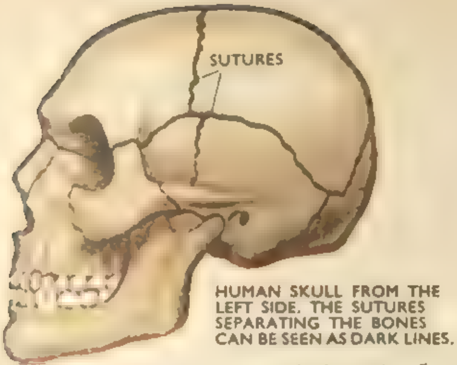
Endoskeletons

Most of the animals which have inner or endoskeletons belong to the group of backboned animals (vertebrates). These include fishes, amphibians, reptiles, birds and mammals, all of which have endoskeletons made of bone or cartilage. A few of the backboneless or invertebrate animals also have a hard inner skeleton; some slugs have an internal shell as does the cuttlefish and its relatives, while some sponges have a rigid internal skeleton formed from interlacing, needle-like structures called spicules.



The hollow parts of a bicycle frame are just as strong as they would be were they solid.



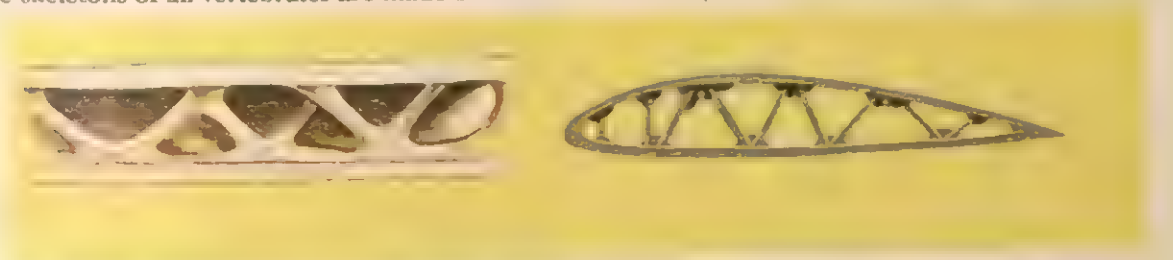


(left) The human hip joint showing how the ball of the thigh bone fits into the socket on the hip girdle. (right) The human knee, a hinged joint.

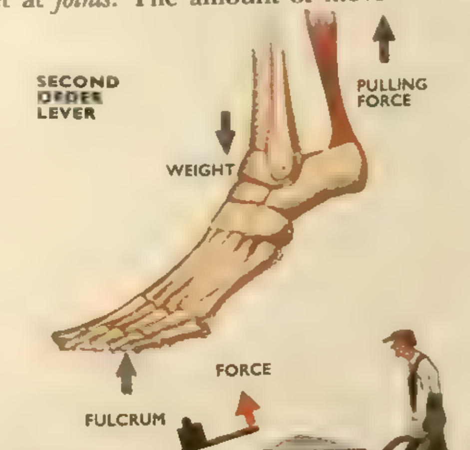
The hard outer shell (exoskeleton) of an insect obviously gives the insect its shape, but even when the skeleton is internal it still determines the basic shape of an animal. Our skull, for example, is very different in shape from that of a dog's, the neck of a giraffe is not like ours in proportion even though it contains the same number of bones (called vertebrae).

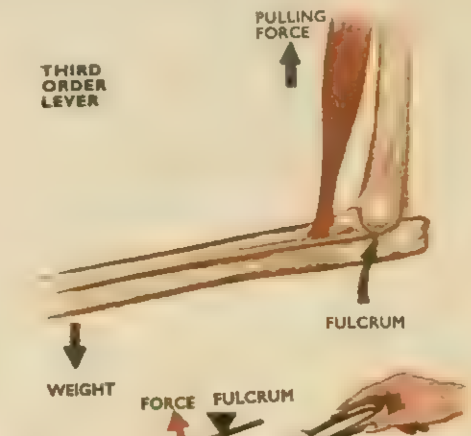
The skeletons of all vertebrates are made of bone or cartilage or both. The main axis of the skeleton is the backbone to which are attached the girdles (shoulders and hips)—from which the limb bones articulate—the skull and the rib cage.

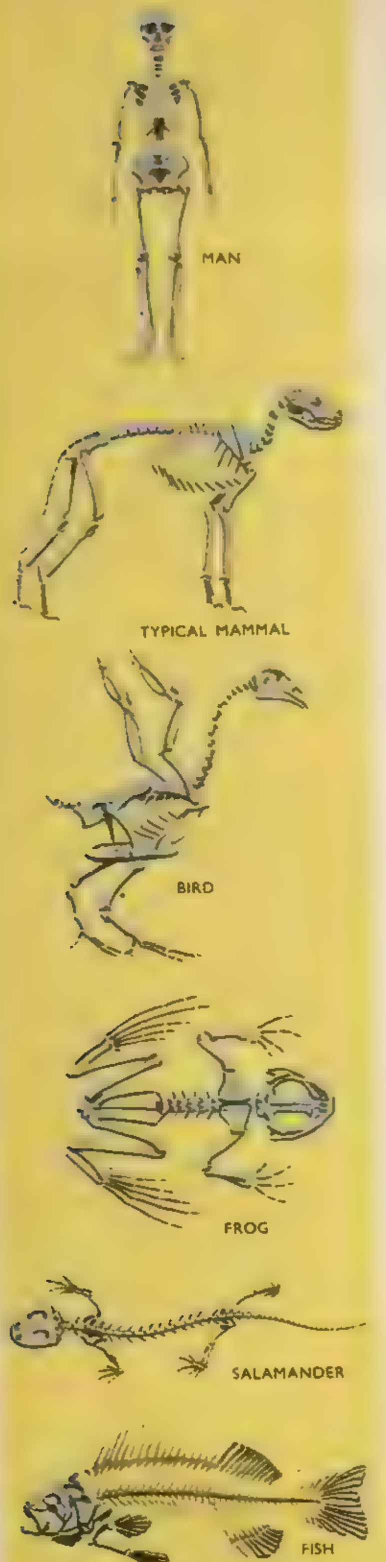
Bones meet at *joints*. The amount of movement depends on the type of joint that there is between the bones which make the joint. The skull, for example, is made up of a number of bones. These move very little on each other. They are separated by thin layers of connective tissue which form the so-called *sutures*. Where there is a little more movement, as between the bones (vertebrae) of the backbone (vertebral column), a pad of gristle joins the bones together.



Part of a wing bone from a vulture showing the internal strutting similar in construction to an aeroplane wing (right). The bone is able to take stresses as well as it would if it were solid and the saving in weight is a great advantage to the bird in flying.







VERTEBRATE SKELETONS

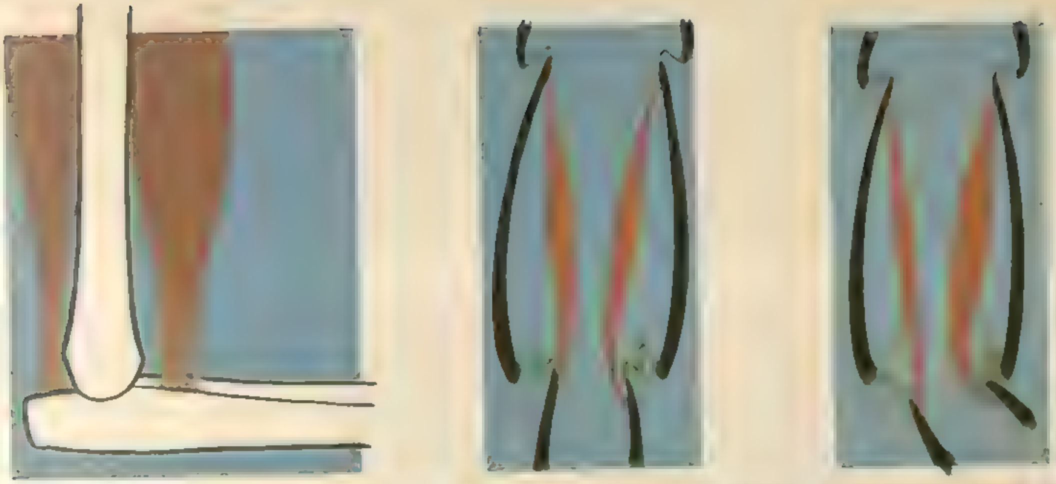
When the bones move freely on each other, as at the knee, hip, shoulder or elbow, the smooth ends of the bones are covered in a thin layer of cartilage. A connective tissue capsule holds the bones together. The inner part of the capsule forms what is called the synovial membrane. This produces a lubricating fluid, the *synovial fluid*. The cartilage, besides reducing the friction between the bones, also acts as a shock absorber so that the bones do not split or shatter when they take severe stresses at the joints (as when a parachutist makes a landing).

The knee is a hinged joint, for the bones move on each other in a similar way to the two parts of a hinge. The leg forms a ball-and-socket joint with the hip. The rounded end of the thigh bone (femur) fits into a socket in the hip girdle.

The construction of the bones is such that they are able to withstand the stresses to which they are usually subjected. The upper third of the thigh bone, for example, is stronger than the lower part, for it has to withstand the greatest stress in this region. In cross-section it is hollow. When a bone is subjected to bending stresses the forces operating on it are greatest at its outside so that the hollow represents a great saving in bone building material, and compared with a solid structure it makes the bone lighter so that the work of the muscles is made much easier. In a similar way engineers reduce the weight and the amount of materials used in building such structures as cranes and bridges by using girders which are H-shaped or are made up of a number of short rods or members (see page 94) joined together in such a way that the strength of the girder is the same. The hollow frame of a bicycle is just as strong as a solid one would be and of course, much lighter. The muscles, too, are arranged in such a way that the stresses on the bones are considerably reduced.

The bones in the body act as levers which are operated by the muscles. There are three main kinds of levers (first, second or third order) depending on the positions of the pulling force, on the position of the weight which is being lifted and on where the lever is pivoted (its fulcrum). The load (weight) lifted divided by the effort or force is called the *mechanical advantage* of the lever. Most muscles work at a mechanical disadvantage; the pull is exerted very much closer to the fulcrum than the weight is.

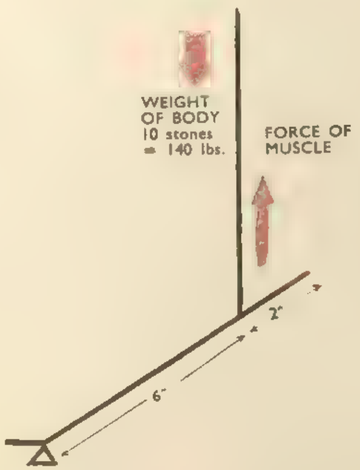
The illustrations show an example of each of the orders of levers. The horse's head is an example of a lever of the first order because the fulcrum is between the weight and the force. The human foot is an example of a lever of the second order since the weight is between the fulcrum and the force,



(left) The human elbow showing the attachment of the muscles to the outside of the skeleton (endoskeleton). (centre) Part of an arthropod limb showing the attachment of the muscles to the inside of the skeleton. Note how thin the skeleton is at the joints compared with other parts. When the right-hand muscle contracts (right-hand illustration) the lower part of the limb is moved from left to right. The left-hand muscle contracts to pull it from right to left.

and the human elbow is an example of a third order lever as the pulling force is between the fulcrum and the weight. Of these three examples the calf muscles, which enable us to stand on our toes, are the only ones to work at a mechanical advantage. In negroes, who have a longer heel than whites, the calf muscles work at a greater mechanical advantage.

PROBLEM



a. A boy stands on one leg and then on his toes. Calculate the force required to do this if he weighs 10 st. and has feet like that illustrated in the diagram.
b. Try to estimate the area of cross-section of the muscle which works here and find the pull per unit area.

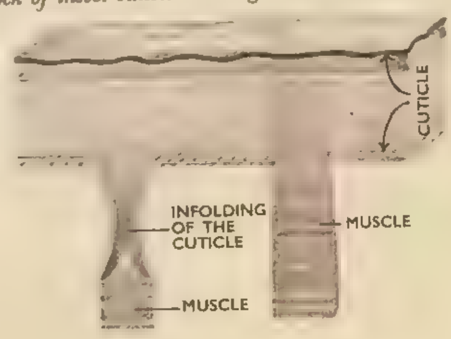
Exoskeletons

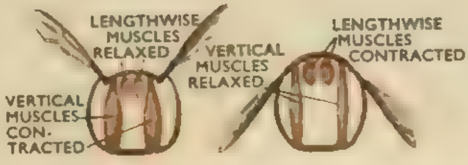
When you eat turkey you take the meat (muscle) from the outside of the bones. On the other hand, with a crab or lobster you have first to crack the shell open before you can obtain the meat from inside it. The shell of a crab is an outer skeleton *(exoskeleton)* and the muscles are attached to its *inside*.

Most kinds of arthropods live on land. The shell provides the support which this environment does not supply (the weight of a water-dwelling animal is supported by the water). The arthropod shell is rather like a suit of armour in that it is jointed, and the muscles are so arranged across the joints that the parts are able to move in relation to each other. The limbs are also jointed and they act as levers moved by the muscles inside.

The exoskeleton besides being protective, providing support and allowing free movement because of its jointing, is also almost impermeable to water in both directions. In a terrestrial arthropod (e.g. insects) water loss due to the drying effects of the sun

A block of insect cuticle showing how the muscles are attached.





Insect flight

The wing muscles are of two main types. These may be called direct and indirect muscles. The former are attached to small moveable plates of cuticle at the bases of the wings and the latter are fixed to the body wall. The direct muscles may be regarded as the fine adjusters of flight; they control the angle at which an insect flies and the direction of flight. They contract and relax slowly. The indirect muscles are the power suppliers. They contract and relax with great speed. Basically they can be regarded as two major sets of muscles, each set working against the other so that when one contracts, the other relaxes and vice versa. One set is arranged vertically, at either side of the body, the other is arranged along the length of the body and between the vertical muscles (see illustration). When the lengthwise muscles contract and the vertical muscles relax the upper part of the body wall (tergum) is arched upwards and the wings are lowered. Contraction of the vertical muscles and relaxation of the longitudinal ones flattens the tergum and the wings are raised. In butterflies and moths, bees and wasps, and two-winged flies (e.g. flies and mosquitoes) the indirect muscles are responsible for producing most of the movement. The direct muscles (they are attached to the wing bases) fold the wings when the insect is at rest and alter the angle of the wing in flight.

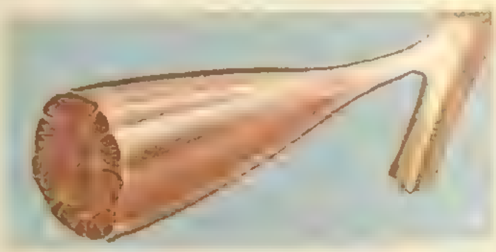
In dragonflies the direct muscles are more important than the indirect muscles in lowering and raising the wings in flight.

During a complete up-and-down movement of a wing any point on the wing maps out a figure of eight in relation to the base of the wing. The wing does not beat up and down at right angles to the length of the body. As it is lowered it is also moved forwards—and as it is raised so it is also moved backwards. During the down-stroke the wing is tilted so that the leading edge is lower than the trailing edge. During the up-stroke the trailing edge is held lower.

is therefore cut to a minimum. The exoskeleton's great disadvantage is that it restricts growth; the body is always outgrowing it. Because of this it has to be shed or *moulted* from time to time. Increase in size can only occur during the short time that the new shell is soft and pliable. An arthropod which has just moulted is defenceless, for its body is unprotected and it can barely move since its muscles have no hard shell on which to pull. Only the young stages of insects moult so that an adult does not grow in size.

Muscles and movement

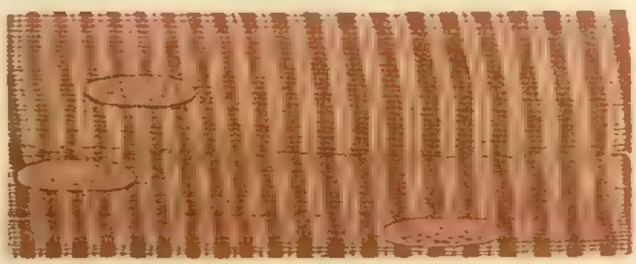
Most animals go out in search of their food. They do so by the action of their muscles. These burn up food, releasing energy in the process, and produce movement of the limbs, or other parts of the body, when they contract (shorten). But muscles are not just organs of movement. Much of the energy unlocked when a muscle contracts is liberated as heat. This is very important in warm-blooded animals—birds and mammals. Their high body temperature



The attachment of a muscle to a bone through a tendon. A muscle may be made up of several large bundles of muscle fibres and each bundle composed of smaller bundles of fibres.

is largely produced by muscular work. Some muscles fix or hold parts of the body in place, acting as ties, giving an animal its posture. Heart muscle moves blood round the body, muscle in the walls of the blood vessels helps to control the supply of blood to various parts of the body, the pipes or ducts from glands contain muscle, and the muscle in the

A highly magnified view of human striped muscle.



Successive stages in the movement of an eel. The red arrows show the position of a wave as it moves backwards along the body of the eel.

wall of the gut, by its rhythmic contractions, moves the food along and helps in its digestion.

The action of a muscle may vary considerably with the demands made upon it. At one extreme the muscles of the arm and hand may work to enable a fast, heavy blow to be aimed with a clenched fist; at the other the same muscles enable the fingers to carry out the most delicate operations.

Muscles are composed of bundles of long cells bound together with connective tissue. This is drawn out at the end of the muscle to form a tendon by which it is attached to the skeleton. When a muscle shortens a part of the skeleton is moved. Muscles are not able to produce movement by pushing; they can only pull and so have to act in pairs, one to pull in one direction and another to pull in the opposite direction.

Over a third of the average vertebrate's body consists of muscle. Apart from heart muscle there are two main kinds of muscle; these are *smooth* (unstriped or involuntary) and *striped* (voluntary or striated). We normally have no conscious control over smooth muscle (hence its alternative name of involuntary), whilst striped muscle (the 'flesh' of the body) can be controlled at will. Smooth muscle includes the muscle of the gut wall, the walls of blood vessels and the lung tubes (these open out when we need large amounts of air

A lizard and a salamander bend their body in a similar way to a fish, though not to the same extent.

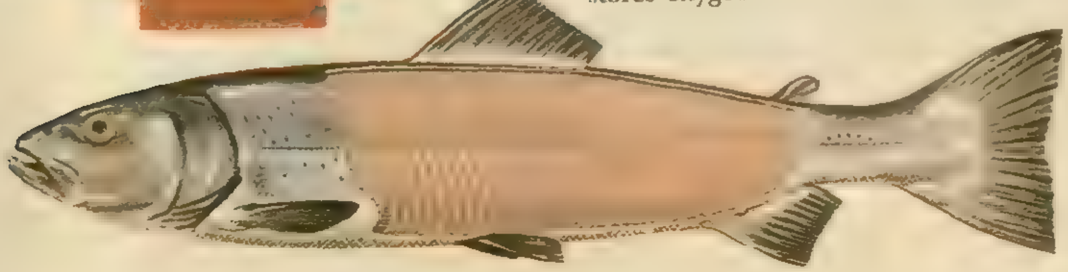
during exercise). It contracts slowly and can maintain this state for long periods. The muscles which control the pupil of the eye, for example, keep the pupil a constant size when lighting conditions do not vary.

Smooth muscles are unstriped in appearance, but striped muscle has prominent stripes which can be seen clearly with the ordinary light microscope.

Striped muscle is able to contract very quickly to produce rapid movement. Its contractions cannot be sustained for such long periods as smooth muscle and it tires quickly.

Striped muscle is generally attached to the skeleton which it moves but smooth muscle is usually arranged in coats or bands. Striped muscle stores oxygen in combination with muscle haemo-

(below) The ≥-shaped muscles of a bony fish. In a fish the fibres within the muscle blocks contract and cause the body to bend.



The sequence of movement when a frog jumps. The long hind legs give it increased leverage in jumping. The stubby forelimbs take the shock of landing.

globin (myoglobin) and it is probable that this oxygen store is available for burning up the supplies of sugar in the muscle.

Typically in vertebrates, for example fishes, the striped muscles are arranged in a series of blocks on either side of the backbone. In the higher vertebrates however, particularly birds and mammals, the limb muscles provide movement and the role of the body muscles is reduced. In fishes, forward movement is produced by contraction of the muscle fibres which are arranged lengthwise in each block. If the fibres in any one block contract the result is a bending of the body. To produce forward movement the fibres of each muscle block contract in one block after another from the front of the fish to the rear so that waves pass backwards down the body, producing a backward thrust on the water. The waves occur alternately on each side of the fish. Rapid production of these can produce very fast movement through the water. The tail fin produces much of the forward motion and, with the pectoral fins, keeps the fish at the same level in the water.

The limbs of nearly all four-footed animals have three main joints; these are the shoulder, elbow and wrist in the forelimbs, and the hip, knee and ankle in the hind limbs. The muscles are arranged so that the limbs can be moved backwards and forwards, bent and extended, and twisted and rotated.

The salamander, when swimming, wriggles its body in a similar manner to fishes. When it walks on land the legs hold the body off the ground and are used as levers moved by the muscles. Frogs have long hind legs which provide for increased leverage in jumping.

Most mammals run about on all fours. The legs are characteristically moved straight backwards and forwards underneath the body. In man both the arms and legs are able to move freely in other directions, though there is more movement at the shoulder than at the hip joint.

In hoofed animals, such as horses, the limbs are lengthened by raising them on the toes. During their evolution some toes have been lost, more usually only one or two remain forming the axis of the limb. Movement is restricted to a fore-and-aft direction, but the arrangement of the joints and the limb muscles makes for very fast running. The hind limbs provide most of the drive, while the forelimbs play the role of weight-bearers.

Many hoofed mammals live in grassland plains where fast movement is both possible and necessary in order to avoid the attentions of the big cats which prey on them. In the cats the skeleton and the muscles are specialized for making the quick leaps with which prey are captured. Much of the weight of the long body is carried on the front limbs.

When a horse is galloping, two feet at the most are on the ground at any one time.

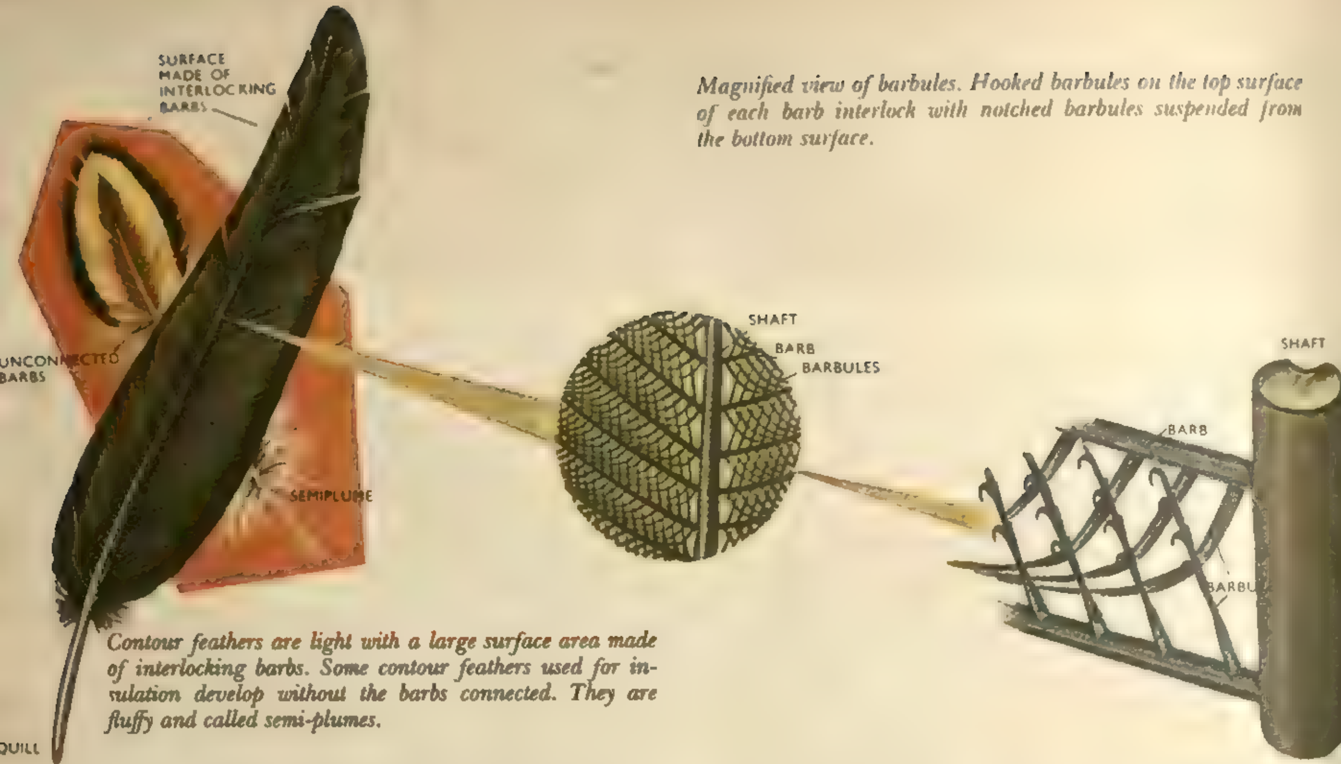
The flight muscles of a bird are large and powerful and may account for a fifth of the body weight. The main muscle is the pectoralis major *and this pulls the wing down. A small muscle, the* pectoralis minor, *elevates the wing. Smaller muscles turn and twist it for manoeuvring.*

Feathers and flight

The one external character that distinguishes birds from all other vertebrates is the possession of *feathers*. Feathers provide an excellent heat insulating layer and also repel water. They are also of prime importance in flight, their colour is important for protective camouflage and also for courtship displays at times of mating. The moulting of old feathers accompanied by replacement with new ones takes place throughout the year, but in birds of temperate climates it is usually seasonal, once during the spring and then again during the autumn.

Feathers are made of *keratin*, a horny protein produced by the outer layers of the skin. They are of four kinds – simple *down feathers* and *pin-feathers* (filoplumes), *contour feathers*, and specialised *powder-down feathers*.

Contour feathers are large and sheathe the body of the bird, as well as covering the tail and wings. The *quill* of the feather is the section which remains embedded in the skin. It is usually hollow with two small openings, one at its base and another where the quill perforates the skin surface. Beyond the quill is the *vane* of the feather consisting of a central solid *shaft* with a large number of side branches (*barbs*) on either side. The barbs are so closely packed together that they appear to form a continuous surface. In fact they are separate units though each one is attached to its neighbours



Magnified view of barbules. Hooked barbules on the top surface of each barb interlock with notched barbules suspended from the bottom surface.

Contour feathers are light with a large surface area made of interlocking barbs. Some contour feathers used for insulation develop without the barbs connected. They are fluffy and called semi-plumes.

by a series of hooked and notched *barbules*.

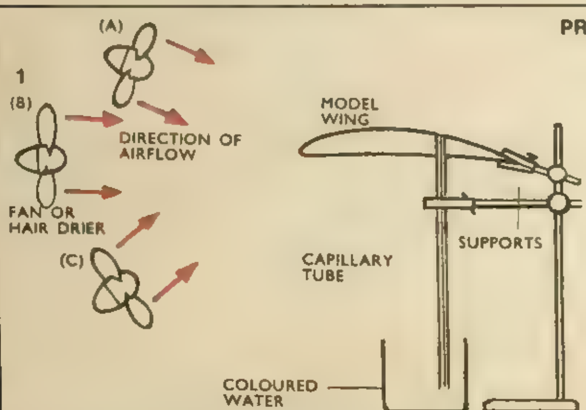
Down feathers are much smaller and simpler, the short quill dividing into smaller branches. The fluffy coats of young chicks are entirely down feathers.

Pin-feathers have a quill and a short stem which divides into a branch of small barbs. Powder-down feathers are possessed by birds such as herons, bitterns, and some hawks. They break down into powder useful for cleaning the rest of the plumage.

In order that a body may travel through the air, two forces must act upon it,. the *thrust* which must overcome the air resistance (drag) and produce forward movement and the *lift* which must counteract the weight of the body and keep it aloft. An aeroplane produces thrust by means of its jets or propellers and it develops lift in the following way. The wings are designed with a curved upper surface and as the leading edge moves through the air the airstream is deflected up over this curved

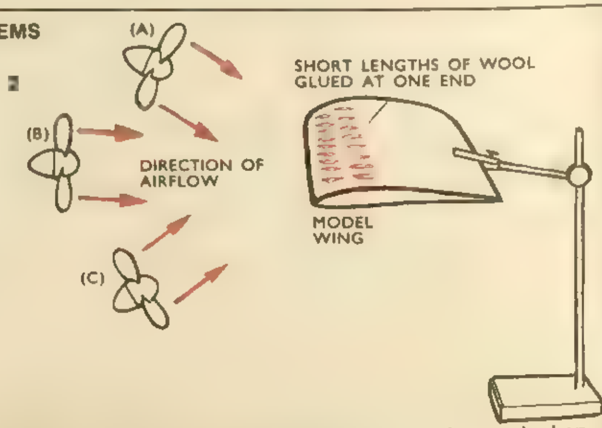
PROBLEMS

1



Construct a model wing—a balsa-framed type covered in paper is excellent—and set it up as shown in the diagram. A fan or hair-dryer is placed in the successive positions indicated. What happens to the water in the capillary tube at (a), (b) and (c) and why?

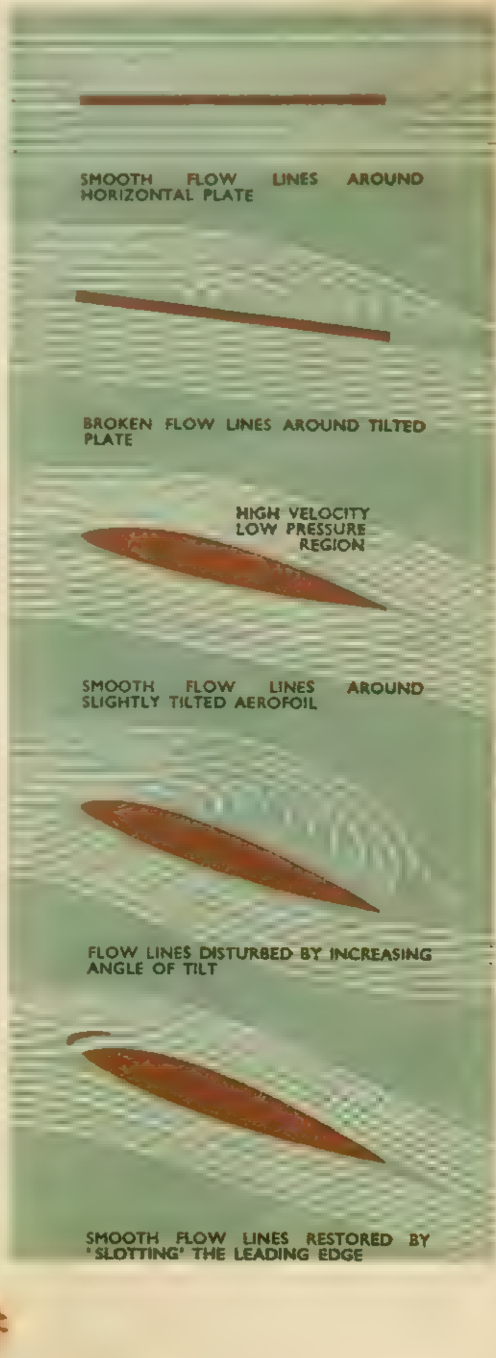
2



Model set up as shown. What happens to the wool when the jar is in position at (a), (b) and (c)?

surface and the air is therefore 'stretched out' relative to the airstream on the lower surface of the wing. This means that there is a slight decrease in pressure on the upper surface and a tendency for the wing to rise or lift upwards. Even a small decrease in pressure per square inch on the upper surface will add up to a considerable lifting force for the whole wing surface. The speed of the airflow and the wing area are important in producing lift. Extra lift can be obtained by tilting the wing upwards at the front. This increases the pressure on the underside of the wing. However, the airflow does not follow the wing surface so closely and above a certain angle the airstream becomes turbulent and lift is destroyed. This is what happens when a plane stalls; a bird only does it on landing. Wing slots guide the airstream over the wing surface more closely, enabling the wing to be angled without stalling. Birds make use of exactly the same principles for flight though a bird's wing has to provide both forward motion and lift. The wing itself is a modification of a five-fingered limb, the wrist and hand bones being reduced and only the second finger being well developed. The large feathers (*primaries*) are attached to the back edge of the hand while the smaller feathers *(secondaries)* are placed on the forearm and upper arm. The feathers are all designed with a stiff leading edge and taper to the back. They overlap each other on the wings so presenting a rigid surface to the air. The shape and curvature of the wing is altered by changing the positions of the feathers by means of muscles and tendons to which all the feathers are attached. The way a bird flies depends on the shape and size of the wings and these vary with the species. A sharply pointed wing stalls at slow speeds due to lack of lift and so is only found in fast fliers (e.g. swifts and swallows) that have well-developed hand feathers and narrow wings generally. Slower-flying birds (hawks) have a wider wing with longer arm feathers to maintain lift. Apart from flapping flight many birds are able to make use of air currents to glide and soar for considerable distances. Large birds such as hawks, buzzards and vultures use rising currents of warm air (*thermals*) and soar upwards in a spiral to considerable heights without once flapping their wings. Gulls soar up to cliff tops by making use of upward currents at the cliff face. Seagulls and the albatross glide over the waves making use of gusts of wind and variable wind speeds at different heights above the waves. The birds gain speed by gliding down-wind and then, on meeting a gust, turn into it to gain height and move into faster moving air further above the disturbed sea surface.

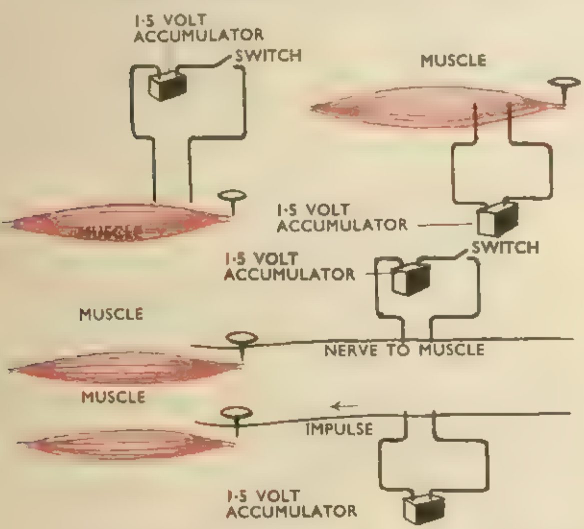
The structure of a typical bird wing showing the attachment of the main feathers.



Co-ordination

CO-ORDINATION BY NERVES—the problem of co-ordination
In an animal body things happen, muscles contract and glands release their products into the gut or blood-stream. It would be catastrophic if all muscles and all glands worked all the time. It is important, therefore, to know what causes a particular muscle or a particular gland to work at a particular time.

If the calf muscle is removed from a recently killed frog it does not contract. It can be made to contract by giving it a small electric shock. We know, therefore, that the muscle is in working order, it is not dead, but before it would contract it had to be 'stimulated' to do so. Somehow the electric shock can cause the machinery of contraction to start.



It is not always necessary to give the muscle an electric shock. If the white stringy fibre (the sciatic nerve) which connects the muscle with the spinal cord is removed with the muscle, it is possible to cause the muscle to contract by giving the nerve a shock at any point along its length. Clearly, something has passed along the nerve to the muscle. By measuring the time interval between the time of 'stimulation' and the contraction it is possible to measure the time taken for the 'thing' to travel along the nerve.

(In frog sciatic nerve about 60 miles per hour, in the nerves of humans about 300 miles an hour.)

It might have been argued that the electric current passed along the nerve, but this cannot be true because the speed at which an electric current passes along a wire is very much faster than this.

The 'thing' is called a nerve impulse. Nerve impulses can be produced by electric shocks. It can easily be demonstrated that injury can also produce a nerve impulse, for example by placing a drop of acid on the nerve.

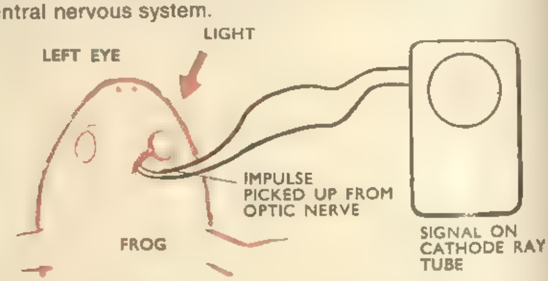
When an impulse arrives along a nerve fibre to a muscle or gland, they are usually caused to work. If a nerve fibre is cut through in the living animal the muscle to which it is connected is paralysed.

The next problem is that of finding out where impulses come from and where they start.

Nerve fibres can be traced from muscles by simply dissecting them out. The nerve fibres from muscles attached to the skeleton have a very simple and regular pattern, they all pass into the *central nervous system*, that is, into the *spinal cord* enlarged at the front end to form the *brain*.

Without going into too many details at this stage, we can classify nerve fibres into (a) those which supply organs which do things, called effector organs, such as muscles and glands, (b) those which supply sense organs, (c) those which connect one part of the central nervous system with another, for example one part of the spinal cord with the brain or to another part of the spinal cord.

Consider a sense organ such as the eye. The optic nerve, a collection of nerve fibres, connects the retina of the eye to the central nervous system.



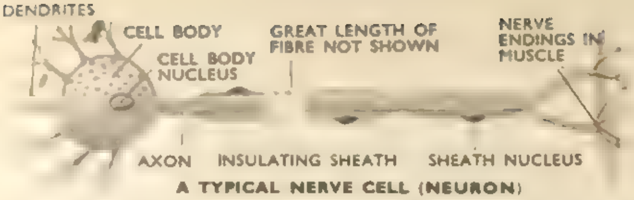
If the optic nerve is cut, sight in that eye is lost. We have no reason to suppose that the eye is not working perfectly as a result of this treatment. Something which normally passed along the optic nerve to the brain (which 'sees') is no longer passing because the nerve fibres along which it passed have been cut. Recently experiments have been performed in which one of a frog's optic nerves was 'wired' up to a cathode-ray tube, such as you find in your television set. When a light was shone on the retina of the eye a signal was received on the tube. What is important from our point of view is that the signal given was the same as the signal which is given by an impulse which passes along any nerve fibre.

We have one answer to our question, nerve impulses start at sense organs when these are stimulated.

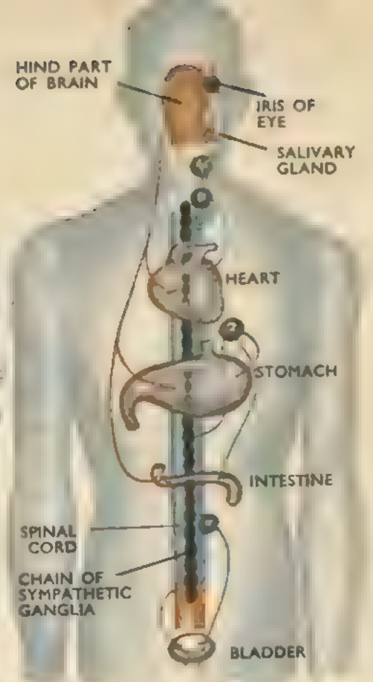
The nervous system

A CAT lies hidden in the grass waiting to spring on an unwary bird or mouse; it turns on its heel and runs at the sight of a dog or alternatively freezes in its tracks, arches its back and hisses violently. In another instant it is carrying out the most delicate cleaning operations. All these actions require great co-ordination—one leg must know what the other leg is doing. Each part of the body must be told when to act and must act in the right way; there must be a regulating system.

These are the tasks of the nervous system in higher animals. The very simplest animals, for example *Amoeba*, have no nervous system, the whole cell responds to changes in the surroundings. In higher animals specialised structures—*receptors* (e.g. eye and ear)—respond to changes in conditions. This results in signals travelling by way of nerves from them to the *central nervous system* (brain and



The structure of a typical nerve fibre.



A simplified diagram of the human autonomic nervous system.

spinal cord). The information conveyed in these signals is combined with the record of past events that is stored in the brain. The decision reached by the brain cells is passed as a signal through a nerve to an *effector* (muscle or gland) which performs the appropriate action. If we are reading a book and the lighting is poor then the signals reaching the brain from the eye are interpreted. Messages to the muscles cause them to contract and so we move and put the light on. The information that the brain has stored from past experiences enables the brain to decide very quickly what is a normal and pleasant situation and what is abnormal and unpleasant.

Besides carrying out these 'reasoned' actions we also perform what are called *reflex actions*. If you place your finger on a hot object you automatically pull it away very quickly. A tap on the leg just below the kneecap causes the leg to jerk upwards. When the leg is tapped a receptor is stimulated and nerve signals pass along a nerve to the spinal cord. Nerves there are stimulated and signals pass along them to the appropriate muscles of the leg which contract and jerk the leg upwards. The brain is not 'consulted' directly in a reflex action; the signal from the receptor passes straight into, and away from, the spinal cord so that the necessary action is produced very quickly. Nerves that carry signals from sense organs are called *sensory* nerves and nerves that carry signals to effectors are called *motor* nerves.

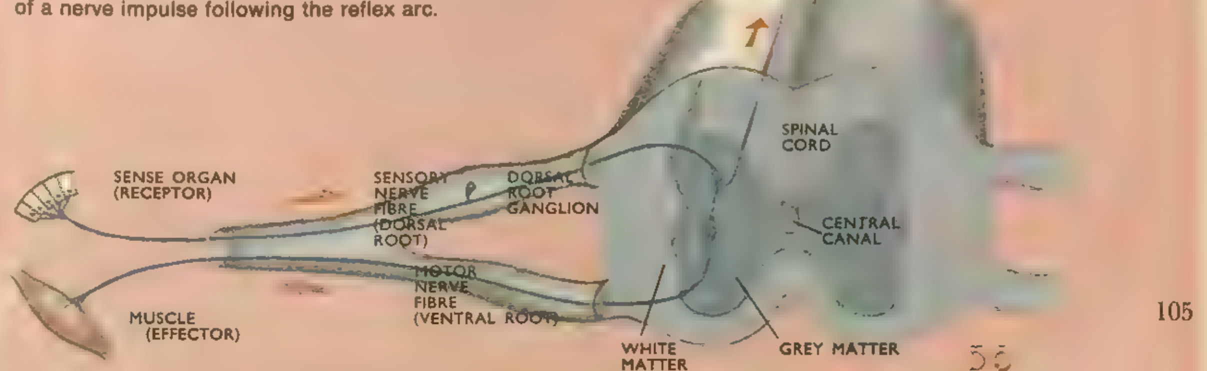
Even though the brain is not involved directly in a reflex action it can modify the action that we take. For example, if a hot, valuable plate is picked up, then the act of withdrawing the arm is often adjusted and we make an attempt to hold on to the plate by juggling with it until we find a suitable place to put it down.

Besides the brain, spinal cord and the nerves passing to and from the effectors and receptors,

When a sense organ (receptor) is stimulated, signals pass from it along a sensory nerve to the spinal cord. The message travels out of the spinal cord along a motor nerve to the effector organ (for example, a muscle or gland) which acts accordingly. Such a pathway is termed a reflex arc. *The sensory nerve fibres of a spinal nerve do not enter the spinal cord at the same place as the motor nerve fibres of the same nerve leave the spinal cord. Sensory fibres enter the dorsal part of the spinal cord and motor fibres leave the ventral part. Sensory fibres are said to have* dorsal roots *and motor fibres* ventral roots. *The cell bodies of sensory nerves are* outside *the spinal cord forming a swollen mass called a* dorsal root ganglion.

The Reflex Arc

The section of the spinal cord and nerve shows the path of a nerve impulse following the reflex arc.



there is another part of the nervous system concerned with controlling the inner machinery of the body. This is the autonomic nervous system which supplies the gut, blood vessels and heart, the lungs, bladder and other internal organs. When an animal is moving its muscles require a greater supply of oxygen than when it is lying down. The heart must beat faster to supply more blood and this blood must provide sufficient food and oxygen, the lungs must be filled with air and emptied more frequently, the blood vessels to the muscles must be expanded and more channels opened up there to cope with the increased supply of blood.

Defensive mechanisms are instinctive. They do not have to be learned. The porcupine erects its quills and rattles them when danger threatens. Cats spit and ruffle their fur; some animals such as the octopus produce frightening colours.

Animal Behaviour

The thrush is not taught to build its nest nor the garden spider to spin its web. These are *instincts* —actions which are inborn and do not have to be learned.

Instincts are common in the animal kingdom, particularly amongst the lower orders of life. They account for much of animal behaviour—courtship displays, protective care of the young, migratory drives and reaction to dangers. The pattern of behaviour begins usually after a stimulus to one or more of the sense organs. Such a stimulus is called a *releaser*. A loud noise—and instinctively, animals take evasive action, fleeing or crouching motionless to the ground. Instincts like nest-building and web and cocoon spinning are perfect from the start. Caterpillars of different species of moth spin their own types of cocoon once only in their lives—but they do it perfectly. Young birds reared in isolation away from parents nevertheless build exactly similar nests even down to the material used. Other instincts such as Man's instinct to walk take time and practice to become perfect.

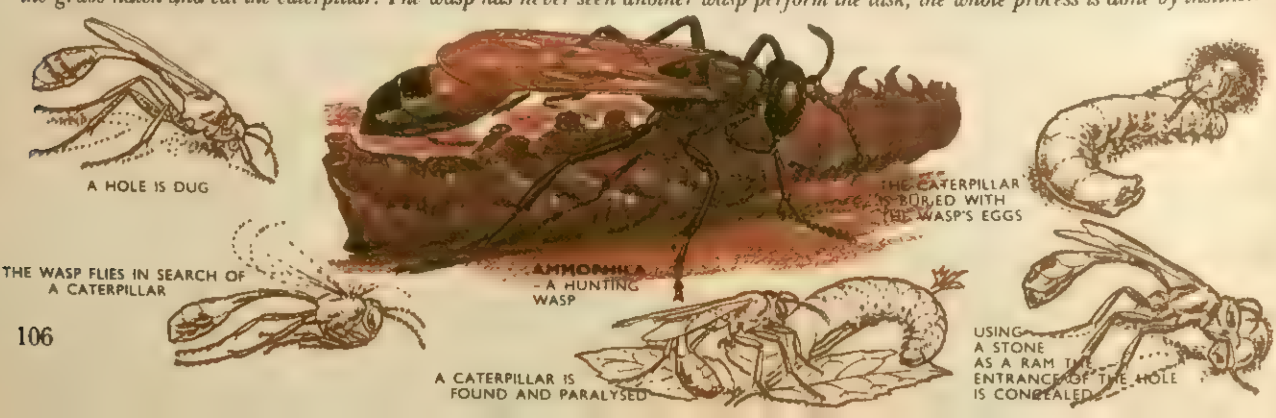
Each species of animal has its own different range and type of instinct. All members of a species will usually behave in much the same way to a stimulus. Instincts are just as much a part of an animal as the structures which identify its body.

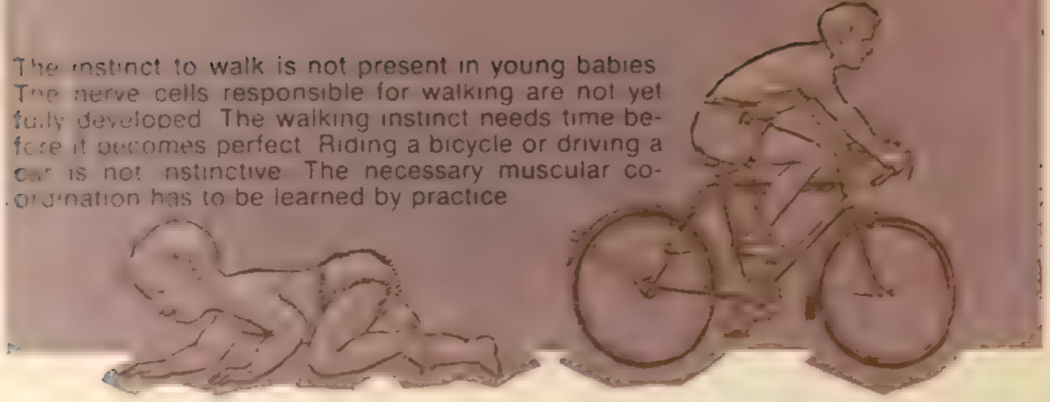
Instincts are purposeful. Although carried out without any learning or reason, they fulfil a definite and usually valuable function. Some are simple enough. A mole bites off the heads of worms it wishes to store for food. The body of the worm remains alive, but devoid of its head, it cannot burrow and escape. More complicated are the engineering feats of the beaver. The beaver fells trees, transports them along specially constructed canals and builds them into dams.

A variety of instinctive behaviour is associated with courtship in different species. The bold parading of pheasant and turkey cocks are common examples. Male redstarts hold a singing contest, ringed plovers demonstrate their powers of flight, whilst deer and many other animals engage in contests of strength.

More amazing are certain impulsive instincts to emigrate from a region. When their populations become overcrowded in Norway, hundreds of thousands of lemmings, vole-like rodents, begin a

This species of hunting wasp performs a complicated series of tasks before laying its eggs. The female digs a hole in the ground. Then she seeks a caterpillar. When one is found she stings it—not to kill but to paralyse—drags it to the hole and lays eggs upon it. Later the grubs hatch and eat the caterpillar. The wasp has never seen another wasp perform the task; the whole process is done by instinct.





The instinct to walk is not present in young babies. The nerve cells responsible for walking are not yet fully developed. The walking instinct needs time before it becomes perfect. Riding a bicycle or driving a car is not instinctive. The necessary muscular co-ordination has to be learned by practice.

colossal mass migration from their homes. Unless a new unoccupied territory is reached the migration continues. The death rate is enormous for the fleeing lemmings are easy prey; many more drown in the rivers and seas they encounter. Similar emigrations have been observed in the springbok of South Africa. Less drastic are the seasonal migrations of birds and animals. Regular passages are made from areas where reproduction takes place to regions in which winter is spent.

Animals which live in communities tend to copy the actions of one another. This instinct is called *mimesis* (mime-EE-sis). Man is no exception to this instinct; if one person yawns others follow suit. The value of all examples of mimesis is not clear. But undoubtedly the copying of others has some survival value. If one animal spots danger and flees, those following also avoid trouble.

Self preservation is a universal instinct in the animal kingdom. Yet when rearing young, the instinct to protect the offspring is often even stronger. Many mammals and birds will stand and fight an aggressor when normally they would have fled. Ground-nesting birds such as the skylark may put on a decoy display. When an aggressor appears, near the nest, the parent bird attracts attention to itself away from the nest by screeching and flapping its wings.

Because there is no forethought or reasoning behind instincts, their function sometimes becomes impaired. The male king penguin, for instance, incubates the egg laid by the female, by supporting it on its feet. If no egg becomes available the penguin will obey its instinct by substituting a round stone. Birds feed their young because the sight of gaping mouths—often brightly coloured—is the releaser to supply food. It does not matter whether it is their own young or not—food is pushed into any gaping mouth. Blackbirds have been known to feed the hungry young of great tits; foster-parents feed the young cuckoo hatched in their nest without any hesitation.

Instinctive behaviour with apparently the least purpose, is found in animals taken away from their natural environments. Dogs still bury bones despite regular feeding; they may even turn around a few times before settling down in their baskets—as though flattening grass into a good bed.

Learning

Instincts regulate the lives of animals like pieces of machinery. An outside action takes place; this provides a stimulus and a fixed pattern of behaviour takes place. Animals which rely largely upon instincts—nearly all except some of the mammals and birds—lack personality. They all behave in much the same way as other members of their species.

Escape from this internal machine is to some extent possible—by a process of *learning*. Learning has the effect of modifying the instinct. Actions no longer take place blindly but are conditioned by past experiences. Two simple types of learning are *habituation* and *association*. In habituation, the initial instinct is lost. Though the old stimulus occurs there is no reaction to it. Domestic animals for instance no longer flee from Man. Association (or conditioning) takes place when the original stimulus is replaced by another. Domestic animals may no longer associate Man with danger but instead with food or comfort.

Association is the method by which animals remember. An encounter leading to an unpleasant experience is avoided at a future date. An encounter which ended in a reward will be repeated. In this manner animals can be trained.

The ability to 'remember' exists to some degree in even simple animals such as snails and worms. By experience of mild electric shocks they learn to avoid making journeys which will bring them in contact with the shock. Bees and wasps certainly have the ability to learn. They soon recognise the landmarks surrounding their nests or hives and are able to move about without losing their way.

By trial-and-error an animal builds up solutions to a number of problems. A dog attempting to reach food on the other side of a fence may come

across a hole in the fence. He remembers the hole on future occasions and when presented with a different fence may again search for an outlet. In this way dogs appear to reason, though all they are doing in fact is remembering similar past situations.

Man has not only the ability to learn by trial-and-error but has developed a further type of learning. This is *insight-learning*—the ability to think out a situation before taking any action. A completely new problem never encountered before is overcome by reorganizing all previous experiences. A solution is not found by the long and troublesome method of trial-and-error, nor is there a similar problem of the past to remember: the brain simply reasons its way forward from a number of general observations and experiences.

Monkeys have been found to possess something of this ability. They have obtained food placed out of reach by piling up boxes one on top of the other and they have used sticks to reach food outside their cages. These are truly reasoned actions for they could never have encountered exactly similar problems in the wild. Dogs, rats and a few other mammals also have some reasoning ability, though usually they only solve a problem of which they have had past experience. The enormous development of insight-learning has helped Man to master the world around him.

This chimpanzee shows signs of insight-learning. Without previously encountering this situation, it uses a bamboo stick to reach out and drag bananas into its cage. Human beings can likewise solve problems which they have never encountered before, only to a much greater degree.

Co-ordination by chemicals

There are changes which take place in animals and plants which can occur even when the nerve supply has been cut or in plants where there is no nerve supply at all.

In plants, roots bend, shoot tips grow, flowers open; in animals bones grow or stop growing, or changes of shape and structure take place as from tadpole to frog or caterpillar to pupa, or a growing animal becomes either male or female. All of these changes and many others have been shown to take place quite independently of the nervous system; yet they are organised. The changes which take place when a frog develops from a tadpole take place 'all over the tadpole'; it is impossible for one part of the tadpole to change into its frog state without the other parts doing so as well.

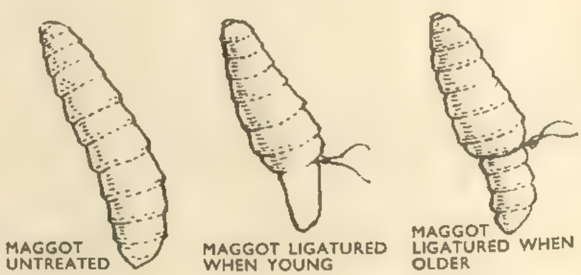
The following practical example helps to demonstrate the problem and suggests solutions which will give a practical foundation to what follows.

When blow-fly larvae change to pupae, they cease to be active, stop feeding, and develop a red-brown hard external skeleton.

Blow-fly larvae in their last larval stage may be treated as follows.

Tie small loops with reef knots and encourage the maggots to crawl into the loops. When the maggot is half-way through pull the loop tight.

Treat ten maggots which have just entered the last moult and ten which are about a week to ten days older. There will be two batches of 300 to 400 per class. Keep a control group of untreated maggots. Observe the results after pupation has occurred in the control group. Compare your results with those illustrated below and answer the questions.



Questions.
a. If ligaturing did not damage the nervous system, is the change under the control of the nervous system?
b. What evidence have you observed which suggests that the nervous system is undamaged?
c. What kind of 'message' would be cut off by the ligature?
d. Where does the message start?
e. Try to account for the difference between the maggots, both treated and untreated.
f. If it were possible to extract chemicals from the front half of an 'old' maggot and inject them into the rear end of a ligatured young maggot, what result would you expect?

Many cells in the body are able to produce fluid and release it. When this is the main job of a cell it is called a *gland cell*; collections of gland cells form *glands*. There are two main types of glands: those which pour out their fluids into a tube or duct (e.g. the digestive glands in the intestine) and those without ducts which release their fluids into the blood-stream. The latter are called *ductless* (or endocrine) glands.

The fluids produced by ductless glands are called *hormones*. They are carried round the body by the blood-stream and act as chemical messengers, stimulating a distant part to action. Chemical signals reach *all* parts of the body; nerve signals reach only certain parts. Chemicals act somewhat like the unpleasant smells released into the air system of a coal-mine as a warning of danger.

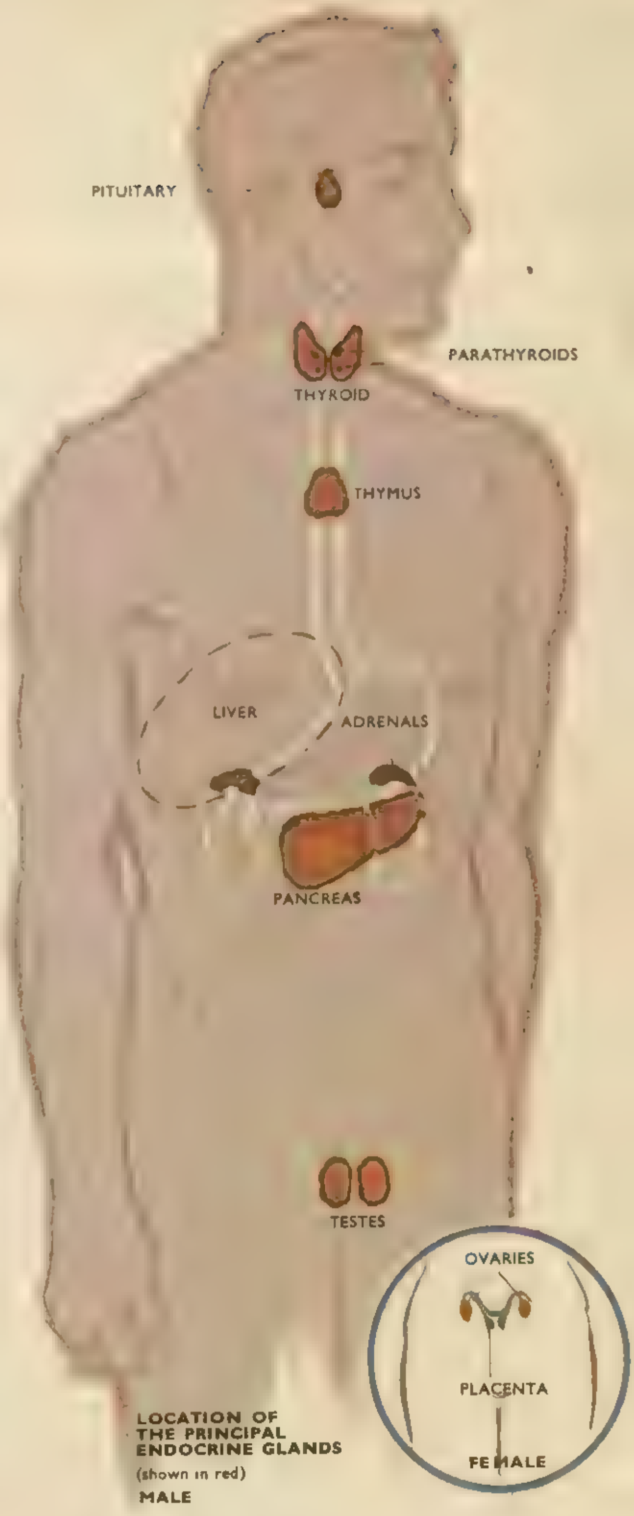
But it is not the task of hormones to be in opposition to the nervous system. The action of the two together is to co-ordinate all the things that are taking place inside the body. Though hormones can act quickly they are more concerned with the long-term running of the body, controlling such things as growth, and the way the body overcomes conditions of stress.

The principal ductless glands are the pituitary, thyroid, adrenals, parathyroids and the ovaries and testes. The liver and the pancreas are dual-purpose glands in that they produce fluids that are not hormones as well as actually producing hormones. The pancreas for example produces pancreatic juice which is rich in digestive enzymes and also makes insulin. The former is released into the pancreatic duct whilst insulin is released into the blood-stream.

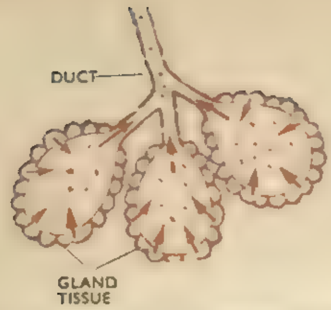
The success of any signalling system depends on the fact that a particular signal always receives the same response. Under normal circumstances a hormone acts on a part of the body in the same way each time. *Adrenalin*, a hormone produced by the adrenals, causes increased heartbeat when a person is frightened and thus prepares him for action.

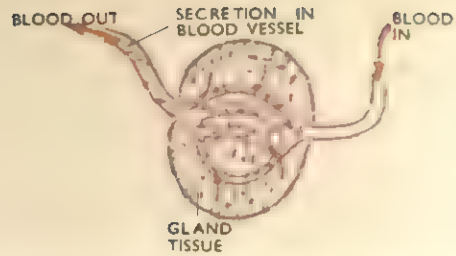
Endocrinology—the study of endocrine glands, their hormones and the effects that these have—is essentially an experimental science. Most of our basic knowledge has been acquired by animal experiments. For example, Sir Frederick Banting and Dr. Charles Best discovered insulin in 1921 during a series of experiments on dogs. As a result we are able to treat insulin deficiency, which leads to the disease *diabetes mellitus* (sugar diabetes), by periodically injecting a special form of insulin.

Though the actions of many hormones are known, it is not known how they act. Why one



The principal endocrine glands in the human body.





*(left) A gland with ducts releases the fluid that its cells produce into the ducts which carry it to the site of action—usually locally. (right) A ductless gland has no ducts and releases its fluids—*hormones*—into the bloodstream.*

hormone should act on one part of the body only and another on practically all cells in the body remains to be explained. But their actions may be grouped under three main headings: 1. *co-ordination*—because they are distributed in the blood to all parts of the body, the body can act as one unit in response to a change in the surroundings or an internal part (the action of adrenalin in this respect has been mentioned). 2. *control of internal conditions*—for example, a hormone produced by the pituitary acts on the kidney tubules, causing them to allow larger amounts of salt to remain in the urine whilst absorbing more water. 3. *growth and development*.

The story of insulin

The events leading up to Banting and Best's discovery of insulin and its subsequent development illustrate the kind of problems that an experimental physiologist encounters, the way that they can be solved and the subsequent development of a discovery.

1889. Johann von Mering and Oscar Minkowski experimentally produced diabetes in dogs, following removal of the pancreas. Further experiments showed conclusively that the pancreas plays some part in controlling the blood sugar level. Surgery without removing the pancreas did not cause diabetes, therefore the operative procedures alone were not sufficient. Until 1920 many workers tried unsuccessfully to alleviate diabetes produced experimentally by injecting pancreas extracts.

The pancreas produces digestive enzymes and Banting suspected that if it also produces a hormone then the digestive enzymes may destroy it in extract form. His experiments were designed to overcome this. He knew that the islet of Langerhans tissue was often degenerated in diabetic patients, which suggested this as the source of hormone. So he tied off the digestive ducts of the pancreas hoping that the digestive tissue would degenerate. Unfortunately the ligatures were inefficient and the tissue did not wither away. So he repeated the experiment using more secure ligatures. The tissue did degenerate and an extract was prepared from the rest of the gland by grinding it up in chilled mortars and placing it in Ringer's solution (this contains sodium, potassium and calcium ions in the same concentrations as in body fluids). All the procedures were carried out at low temperatures and in thoroughly cleaned vessels. Although Banting and Best did not realise it at the time the low temperatures suppressed the activity of any remaining digestive enzyme, so that the activity of the extract was not affected.

July 1921. Injections of extract were injected into diabetic dogs. At first no startling results were obtained but repetition of their experiments showed that high blood sugar levels were reduced. The substance that must be present in their extracts they named *isletin* (subsequently the name *insulin* was adopted). They injected sugar into dogs to deliberately raise the blood sugar to astronomical levels and still succeeded in lowering it to normal. In some cases overinjection of extract produced low blood sugar levels. In their initial experiments they obtained 74 successful results on ten separate diabetic dogs. Having shown that an extract worked they set about trying different methods of preparation to find the best method and also to establish the optimum range of conditions under which the extract was most effective. They showed that trypsin in pancreatic juice did destroy the extract's potency. Later they discovered that a potent extract could be prepared by immersing whole pancreas in acidified alcohol, so that the laborious procedure of tying off the digestive duct had been unnecessary.

January 1922. After more exhaustive tests an

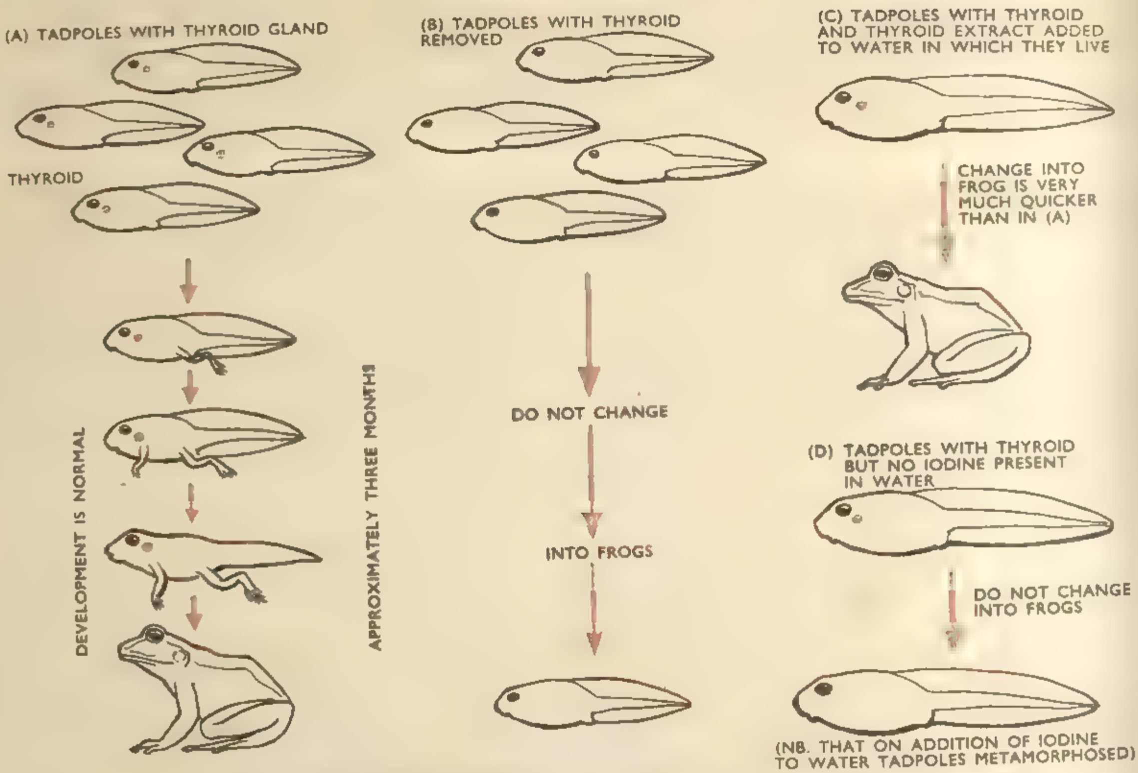
extract from cattle pancreas was prepared in an attempt to alleviate diabetes in Leonard Thompson, an eleven-year-old boy in a Toronto hospital. All symptoms were relieved after a continuous course of treatment. Previously they had tested the extract on themselves to test for any possible reactions.

In the same year commercial production of insulin was started. Since that time purer and better forms of insulin have been prepared and tested until today even a diabetic child can administer its own daily injections of insulin.

GLAND	HORMONE	ACTION
Pituitary —anterior	Growth hormone	Affects growth processes of all body cells. Too much hormone causes gigantism, too little produces a pituitary dwarf.
	Thyrotropic hormone	Acts on the thyroid gland causing it to produce quantities of thyroid hormone.
	Prolactin	Causes the mammary glands to produce milk.
	ACTH (adrenocorticotropic hormone)	Causes adrenal cortex to release its hormones.
	Sex hormones (2)	One causes ovaries of female to produce eggs and testes of male to manufacture sperms. A second causes thickening of the womb lining to prepare it to receive a fertilized egg and growth of the placenta if the egg is implanted.
—posterior	Oxytocin	Causes the womb to contract and so expel the child at the end of pregnancy. Also causes increased production of milk in the mammary glands.
	Vasopressin (ADH)	Controls loss of water and salt from the kidneys in the urine, reducing water loss but promoting the loss of salt.
Thyroid	Thyroxine Triiodothyronine	Increase the rate at which chemical reactions proceed in all cells and so affect growth. Production of too little hormone in childhood causes cretinism: the child is physically and mentally backward. In adults too little hormone causes increase in weight, puffiness, thickening of the skin, coarse and brittle hair, and mental and physical actions are slowed down to such an extent that a drowsy, lethargic state results (myxoedema). In the condition of exophthalmic goitre the gland is very enlarged due to lack of iodine in the diet.
Adrenals —medulla (central part)	Adrenalin	Produced during sudden fright for instance, preparing the body for action by increasing heartbeat, increasing blood supply to muscles and reducing it to gut and skin. Blood sugar released from liver to supply more fuel.
—cortex (outer part)	Group of hormones called steroids	Prepare the body to meet conditions of stress on a long-term basis (as in pregnancy, illness etc.). The exact action of steroids is not known but they appear to be concerned with respiration and energy production in all body cells. Steroid production is stimulated by ACTH of pituitary.
Pancreas	Insulin	Acts on the cells enabling them to use glucose for providing energy, and so controls the blood sugar level. Underproduction of insulin results in too high a blood sugar level and the ultimate appearance of sugar in the urine—sugar diabetes or *diabetes mellitus*. Overproduction of insulin depletes blood sugar to abnormally low level—as serious a condition as diabetes.
	Glucagon	Recently discovered. Exact role in body not known but has opposite action to insulin and in this respect is similar to adrenalin.
Parathyroids	PTH (parathyroid hormone)	Connected with the metabolism of calcium in the body, increasing its uptake through the intestine. Removal of parathyroids causes tetany —continued contraction of muscles due to the disturbance of muscle and nerve fibres.
Reproductive organs (testes, ovaries and placenta)	Several	Control of sexual maturity, secondary sexual characteristics (growth of hair, mammary glands, etc.) and activities such as the menstrual cycle, pregnancy and production of milk by the mammary glands.
Thymus	Thymus hormone	Recently discovered in mice and thought to control the development of immunity. (Not yet demonstrated in man.) Manufactures lymphocytes.

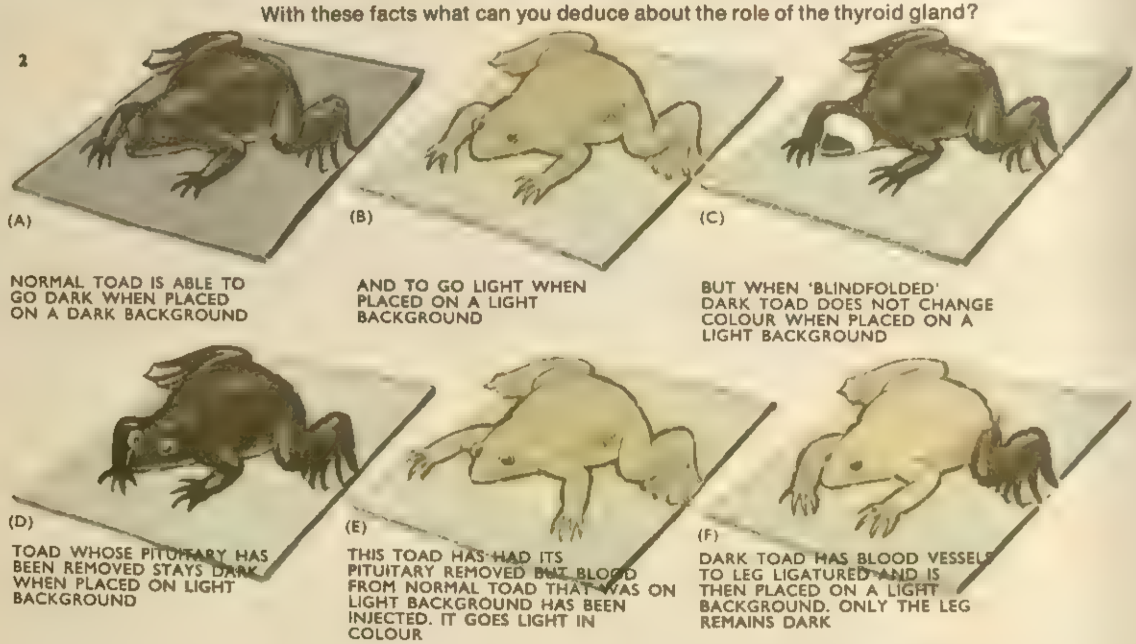
PROBLEMS

TADPOLE METAMORPHOSIS

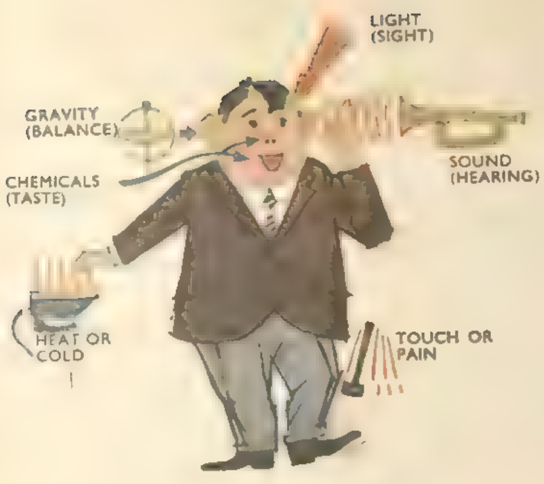


With these facts what can you deduce about the role of the thyroid gland?

2



What deductions can you make about the way in which change of colour may be controlled?



A SUMMARY OF THE STIMULI TO WHICH WE RESPOND

Insects are well equipped with taste and smell receptors. An elephant hawk moth uses its proboscis to obtain nectar from a honeysuckle flower. Inset: the feeler or antenna of a moth (enlarged) on which smell receptors occur.

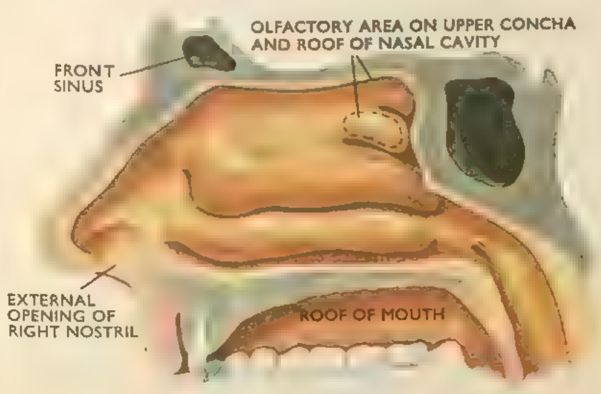
The Senses

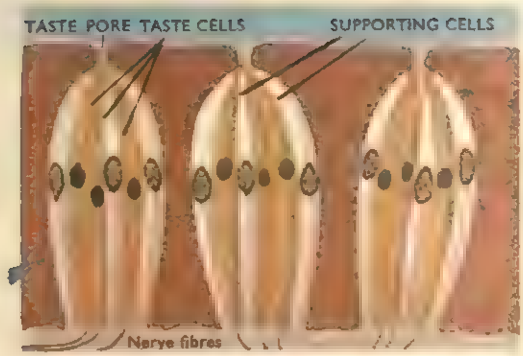
Living things respond to the surroundings—heat, light, sound, chemicals etc. Their success or failure depends on whether they make the right responses or not. A human has a variety of sense organs *(receptors)*, which respond to a whole range of stimuli. Besides the senses of sight, smell, hearing, touch and taste, there are many others including balance, hunger, thirst and we are also sensitive to heat, cold, pressure and pain.

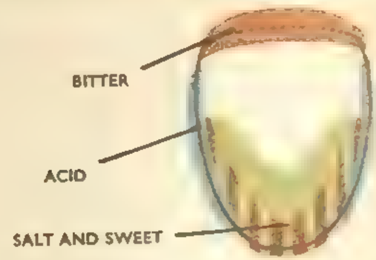
The skin, which is in contact with the surroundings, is richly supplied with receptors. This means that if contact with an object is painful a part of the body can be moved rapidly away before too much damage is caused. Similarly a pleasant sensation may result in a further movement towards the object encountered. Some areas of the skin are more sensitive than others. The soles of the feet, the palms of the hands and the lips are particularly sensitive. Nerve endings of various kinds are scattered through the skin and respond to touch, heat, cold, pressure and pain. Hairs are very sensitive. Receptors inside the body are also responsive to stimuli. A duodenal ulcer, for example, gives the sensation of pain.

The organs of taste and smell are sensitive to chemicals; those for taste occur mainly on the tongue, a few elsewhere in the mouth and throat. Small projections on the tongue have flask-shaped *taste buds* scattered over them. When the taste buds are stimulated signals pass from them along nerve fibres to the brain. The taste buds are moistened by saliva and the fluids produced by special gland cells in the tongue so that the chemical passes into solution before it stimulates the receptor. During dry, cold weather the sense of taste is much reduced. By testing the reaction of different parts of the tongue to different substances it has been shown that the greatest response for each of the four 'types' of taste—salt, sweet, acid and bitter—is in a different region of the tongue. The tip is most sensitive to sweet and salty substances; the sides to acid substances and the back to bitter substances.

The right half of the nose cavity of a human viewed from inside showing part of the area of smell.



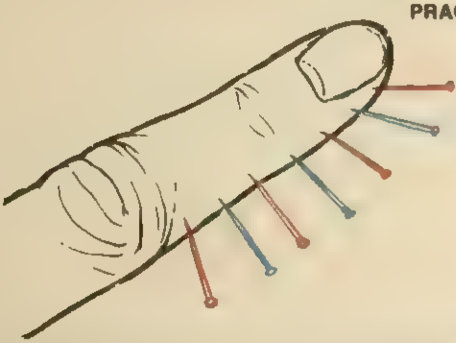


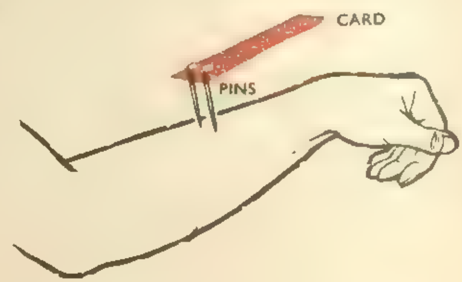


A view of the human tongue. (right, above) A diagram showing a section through three groups of taste cells. (below) Areas most sensitive to the four main taste qualities.

The organs of smell are embedded in the lining tissue of the nose, on the roof of the nasal cavity. All have the same structure yet we can appreciate a wide range of smells. The tastes or flavours other than the four basic ones are strictly part of the sense of smell dependent upon the receptors in the back of the nose.

PRACTICAL PROBLEMS





1. Map out the cold and hot spots using a pin chilled with ice or heated in water on the finger of a blindfolded subject. Use also a pin at room temperature. Is there any distinction between the distribution of temperature and touch receptors?

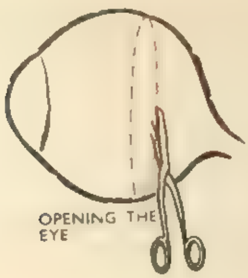
2. (a) Using this card find point at which 2 points close together can be distinguished as 2 varying distances of pins from each other.
   (b) Which parts of the body are most sensitive in this respect?

3. Test various parts of hand to see which are most sensitive to heat, cold, touch etc.
4. Place different substances on the tongue and note which parts are sensitive to what.
5. Clip and unclip nose. Test tongue with onion and apple juices. What is the significance of results?

SIGHT

Practical work on the eye – dissecting a cow's or sheep's eye

1. Remove the creamy white fatty tissue from around the eye carefully.
   Find the external muscles. What do you think these do?
   Find the optic nerve.
   Draw the eye from the front and the side to illustrate its structure.



2. Opening the eye.
   The eye is opened by cutting around an equator parallel to the front of the eye a little behind the mid-line.
   With the point of a sharp scalpel cut through the outside of the eye by short 'scraping' cuts. Now cut round the equator with a pair of scissors.
   Have a large watch glass ready to receive the contents of the eye.
   Describe the properties of the outer coat of the eye.
   Describe the contents of the eye.
   Complete the cut and turn each half inside out.
3. You will now have three parts: the front half, turned inside out, the back half also turned inside out, and the contents of the eye.

   The contents
   Identify the vitreous humour which usually comes out with the lens attached.
   Now gently remove the lens from the vitreous humour Investigate the properties of this lens. Describe its shape. Is it nearly spherical or markedly flattened? Is it transparent or opaque (a lot will depend on the freshness of the eyes – they should be as fresh as possible and will not keep in a fridge)?
   Place the lens between two small watch glasses. Hold the lens near to, and parallel with, the plane of a sheet of white paper and produce an image of a distant object outside the window. Describe the image produced. In order to focus the image it will be necessary to move the lens relative to the sheet of paper.
   Try to measure the focal length of the lens.
   What CONTROL EXPERIMENT is necessary here?
   The front part of the eye
   Identify the iris diaphragm and the corneal surface. Try to find the remains of the suspensory ligaments. Is the cow's eye similar to a human eye in this respect?
   The back part of the eye
   Describe the retinal surface, i.e. the inside surface of the back of the eye. Find the inside end of the optic nerve. What is attached to it?

Some questions for you to discuss.

a. Can an eye see?
b. If the optic nerve is cut, sight in that eye is lost. Has that eye stopped doing what it would have been doing if the optic nerve had still been intact?
c. Does a picture go along the optic nerve?
d. Lay your first finger of your left hand across the bridge of your nose pointing to the right. Gently touch your eyelid (right eye). Now look to the right without turning your head. What do you see? When you see the image, move your finger up and down a little way. Which way does the image move in relation to the direction in which you move your finger?
   How is it that you see something which is not there?
   Is the retina only sensitive to light?
   Why does the 'phantom' move the wrong way?
   What has the brain to do with all this?
   If it were possible to attach the nerve from your ear to the cut end of the optic nerve so that impulses passed from the ear nerve along the cut optic nerve to the brain, what do you think would happen if you stood near a recording of Beethoven's Moonlight Sonata?

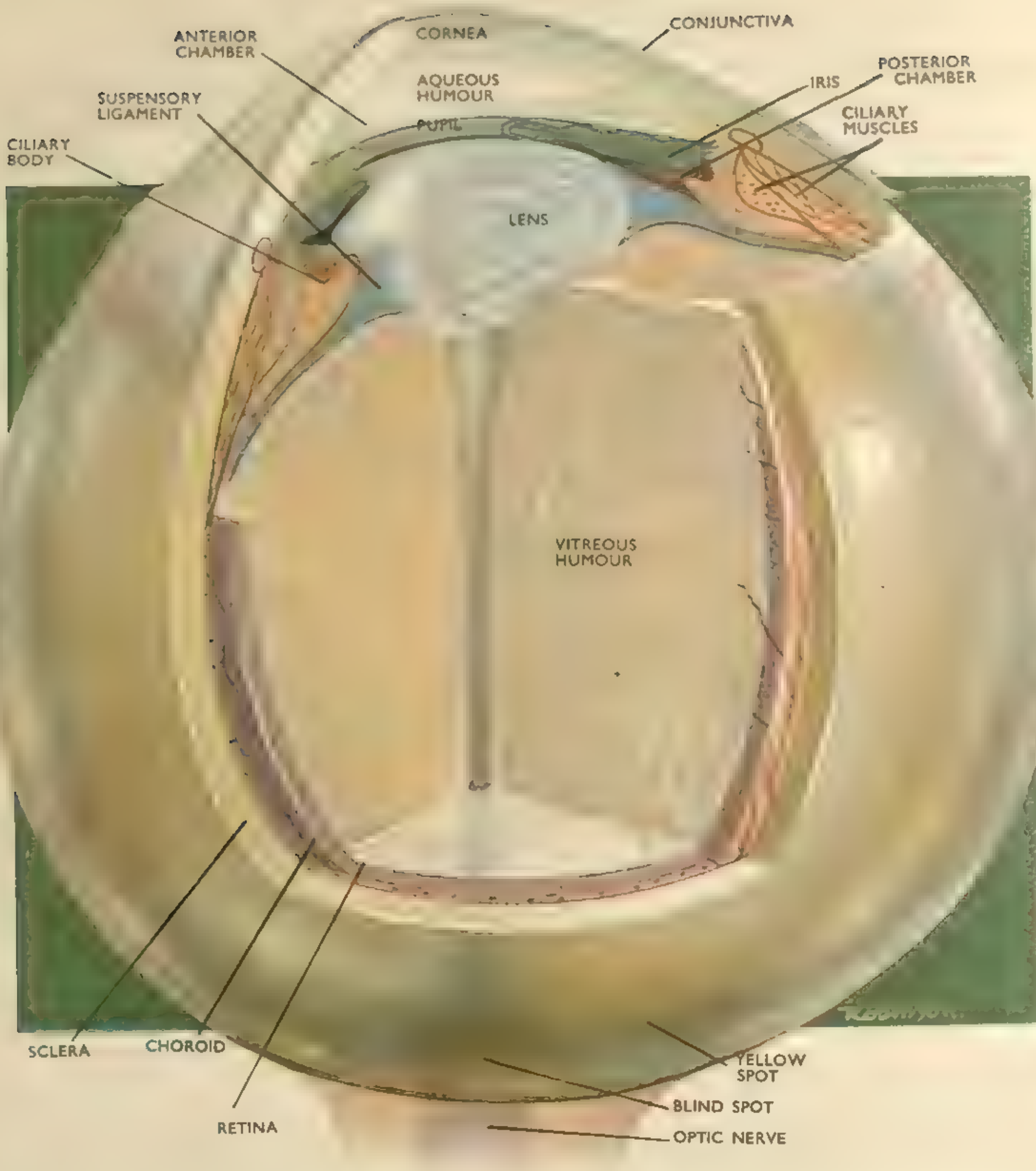
The problem of 'seeing clearly' objects at different distances from the eye

1. Look out of the window at a distant object. Now place a finger about six inches in front of your right eye. If the distant object is seen clearly, is the finger seen clearly? and vice versa. Why can't objects at different distances be focused on a screen at the same time?
2. Make up a ray box by fitting an electric light bulb inside a syrup tin with a number of small holes over an area about 2 in. by 2 in. in one side. Fill a large beaker with water to which a little fluorescein has been added. Shine the rays of light through the fluorescein. Now place a lens in front of the point where the light enters the beaker and observe what happens to the rays of light. Use a different shaped lens and compare the effects. In general, what is the difference between the effects produced by 'fat' lenses of small radius of curvature and 'thin' lenses of large radius of curvature?
3. When a lens is removed from a cow's eye it is almost spherical in shape; it has a small radius of curvature. How could such a lens be made to focus distant objects on a screen in the same position as the retina?

Sight in Man

The eyes in man detect light in the surroundings. Heat receptors in the skin and some other parts of the body are the only others sensitive to radiation. The eyes are only sensitive to wavelengths within the 'visible' spectrum but some animals can detect radiations outside this. Many insects, for example, can detect ultraviolet light. Humans cannot detect ultraviolet light.

Each human eye is a hollow, spherical organ filled with fluid. The pressure of this maintains the shape of the eye. The eye wall has three main layers, a tough, fibrous outer coat – the *sclera*; a layer inside this containing pigment and blood vessels – the *choroid*; and an inner lining – the *retina* – which contains the light-sensitive cells. At the front of the eye



A drawing of the human eye magnified about five times and partly cut away to show its internal structure.

the sclera, which is visible as the white of the eye, is transparent and forms the *cornea*; this is covered by a thin transparent protective layer, the *conjunctiva*, which becomes inflamed in the condition of 'pink eye' *(conjunctivitis)*. The choroid forms the *iris*, the visible blue or brown pigmented part of the eye, in the centre of which is an aperture, the *pupil*. The swollen outer part of the iris is the *ciliary body* which contains muscle. The action of this is to alter the shape of the lens and thus its focal length. The lens is a transparent, crystalline structure suspended from the ciliary body by the suspensory ligament. The retina ends just behind the attachment of the suspensory ligament.

The iris divides the part of the eye in front of the lens into anterior and posterior chambers. These are filled with watery fluid, the *aqueous humour*, and the hind chamber contains the thicker, more jelly-like *vitreous humour*.

Each eye is protected within its bony socket or *orbit* in the front of the skull. The eyelids close together quickly when the eyeball is touched and

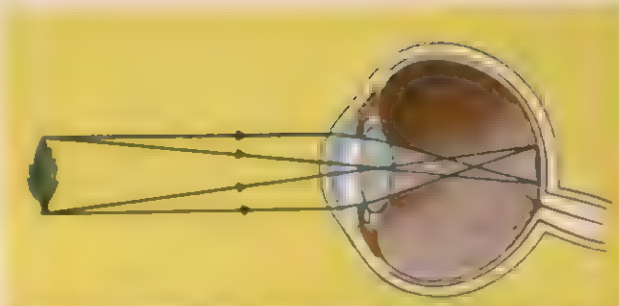
when an object is moved rapidly close to it. By blinking every few seconds the eyelids bring down liquid from the tear glands. This keeps the cornea moist, nourishes it and also washes away grit and dust. The eye is moved in its orbit by the action of six eye muscles. Those of each eye are co-ordinated, so that normally both eyes are moved in the same direction.

Light enters the hind chamber of the eye after passing through the cornea, pupil and lens. The cornea forms an important part of the focusing mechanism, bending the light far more than the lens does. The latter produces a sharp image on the retina.

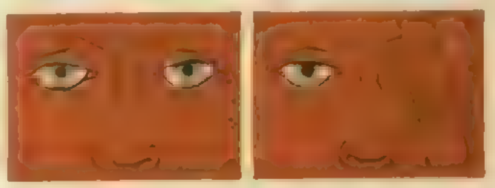
The iris may be compared with the aperture (iris diaphragm) of a camera. The size of the pupil automatically varies with the light intensity, being just a pin-hole in bright light and so cutting down the amount of light entering the eye, and opening out in dim light to increase the amount of light entering the eye.

The shape of the lens can be altered so that either images of close or distant objects can be focused on the retina. This is called *accommodation*. If the tension on the suspensory ligament is relaxed (when the ciliary muscles contract and resist the pull of the sclera) the lens becomes fatter and a close object comes into focus. When the ciliary muscles relax the sclera pulls on the suspensory ligament and the lens is flattened bringing distant objects into focus.

Basically the retina contains two kinds of light-sensitive cells called *rods* and *cones* because of their shape. Where the optic nerve leaves the eye there are no light-sensitive cells and the region is known as the *blind spot*. A short distance away from this most of the cones are concentrated in a shallow depression, the *yellow spot* or *fovea centralis*. It is the region where the light is principally focused and only the part of the image which falls on the fovea is seen sharply. This is because the cones are so small and closely set together. They are sensitive to colour. The whole of the rest of the retina contains rods, sensitive to weak light but not showing colour. For this reason we see no colour by moonlight, but see in greys and silver. Many animals that go out at night have few cones in their retina and some (e.g. bats) have an all-rod retina.



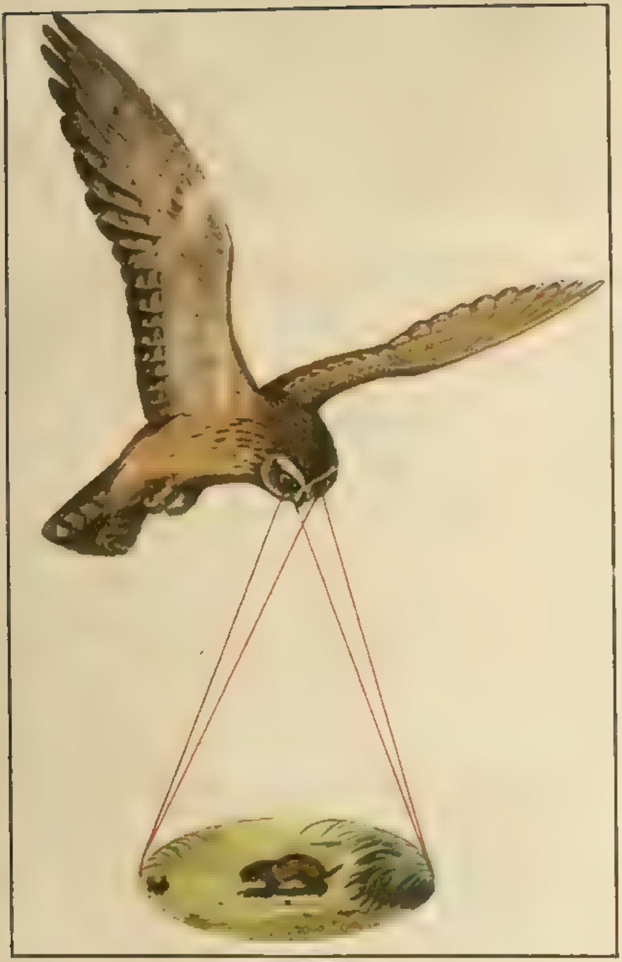
A diagram showing how the cornea and lens focus an image on the retina at the back of the eye



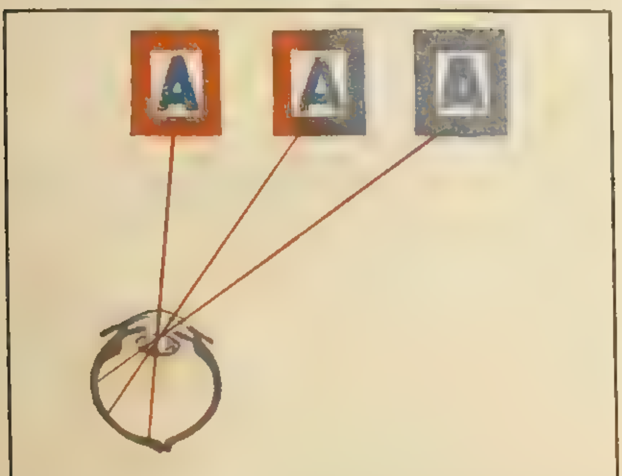
In daylight the pupils are small. When one eye is covered the pupil of the other widens as the result of a reflex linking up the two eyes.

(right) In dim light the pupil is wide open to admit as much light as possible. (left) In bright light the pupil narrows to cut down the amount of light falling on the retina.

H



An owl has both eyes at the front. Its vision is said to be binocular.



An object focused on the edge of the retina is blurred and colourless. As it is moved to the direct line of vision it becomes more distinct and coloured.

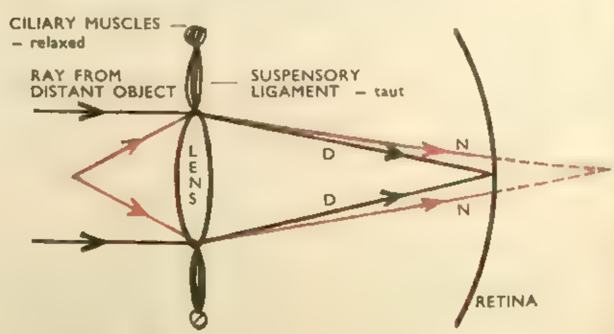
The Blind Spot.

Hold a page up so that the dot and the cross are about two feet away from your eyes. Shut your right eye and look at the cross with your left eye; as you do so, very slowly bring the paper towards your eyes. Although you are looking at the cross you can still see the dot. Then, at a certain point, the dot seems to disappear; it is then focused on the blind spot. As the page is moved forward it reappears. Measure the distance when the point seems to disappear.

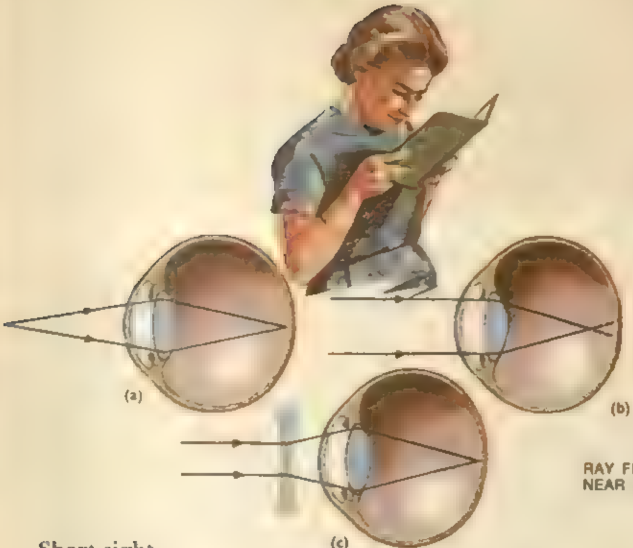
In many animals the eyes are in the side of the head. Each eye has a distinct field of view; vision is said to be *monocular*. But others (birds such as owls and primates including man) have *binocular* vision. The eyes are in the front of the head and their fields of view overlap.

Eye defects

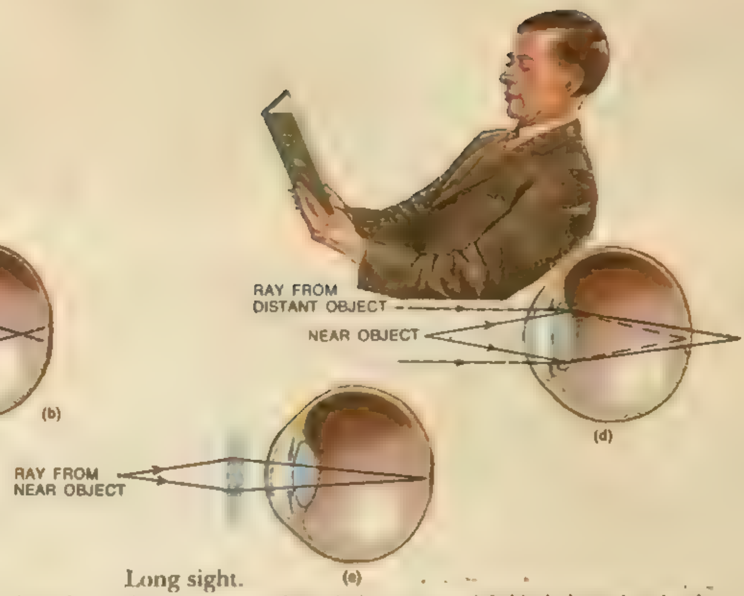
Very few people have perfect eyesight and most people at some time in their lives will need spectacles. Most eye defects develop as we grow older, and are due to lens defects. A *short-sighted* eye is one which can focus near objects clearly but which cannot focus distant objects; the focal point is in front of the retina. It may be due to distortion of the retina—the eyeball is too long—in which case the person is born with the defect, but more frequently the lens is too fat. Often short sight is exaggerated by straining the eyes by reading too much, or watching too much television, especially in poor lighting conditions, when strain on the eyes is much greater. Short sight may be remedied by spectacles with diverging lenses. These spread the light out making the rays seem to come from a nearer object so that they are focused on the retina and not in front of it.



Distant object in focus



Short sight.
(a) A near object can give a clear image.
(b) For distance viewing the short-sighted eye gives a blurred image as the light is brought into focus in front of the retina.
(c) A diverging lens is used to correct this.

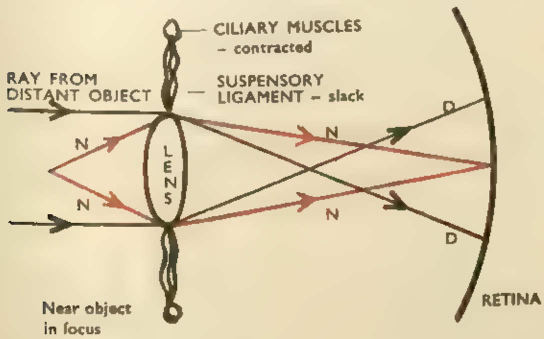


Long sight.
(d) For a near object light is focused behind the retina in the long-sighted eye when the ciliary muscle is fully contracted and the lens as spherical as possible. (e) A converging lens corrects this defect.

A *long-sighted* eye is one which can focus distant objects but not near objects. The focal point is beyond the retina. The eyeball may be too short or the lens may be flatter than normal so that its shape does not change so as to focus a near object onto the retina (see diagrams). Long sight may be corrected by converging lenses which bring the light rays together and focus them on the retina and not beyond it.

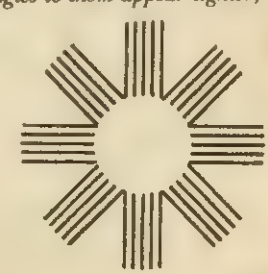
As you grow older there is a natural tendency for the lens to harden with a somewhat flattened shape so that it does not become fatter when the ciliary muscles contract. This defect is corrected by spectacles with diverging lenses as for long sight correction.

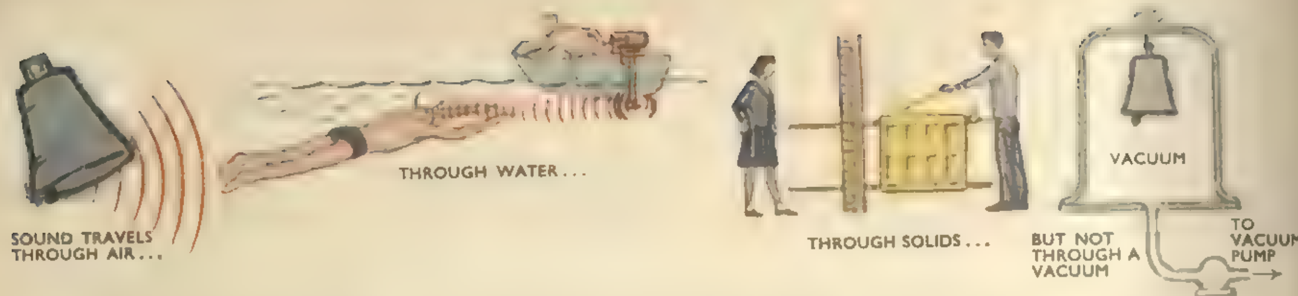
Another common defect is *astigmatism*. This is the inability to focus on horizontal and vertical lines at the same time, such as the struts of a window frame.



The lens does not have an equally curved surface and so some parts of it focus more strongly in one plane than another. Astigmatism is corrected by means of a special cylindrical lens which gathers up the light rays in the plane where the extra bending is needed.

Are your glasses corrected for astigmatism?
Hold them horizontally about two feet away from your eyes and look at the corner angle of a doorway or window. Then tilt the glasses. If the corner appears to tilt as well then the glasses are corrected for astigmatism.
Do you suffer from astigmatism?
Shut one eye and look at this picture. If all the lines appear equally dark, you do not. If some sets of lines appear darker and those at right angles to them appear lighter, then you do.





Sound is transmitted through water, air and through solids. But it is not transmitted through a vacuum; a bell ringing inside a bell jar containing no air is not heard outside the bell jar, because there are no air molecules to vibrate.

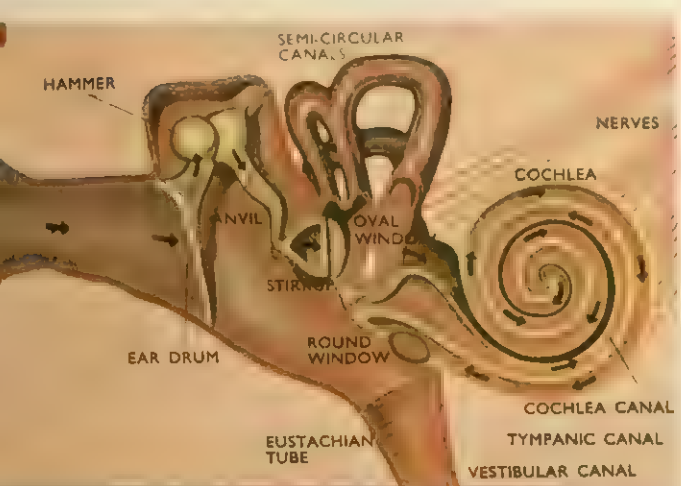
Hearing and balance

When a guitar vibrates it causes the surrounding air molecules to vibrate, which in turn cause adjacent molecules to vibrate. In this way the vibrations set up by the string are transmitted to our ears as sound. Sound waves are not transferred through a vacuum, for there are no molecules to carry the sound.

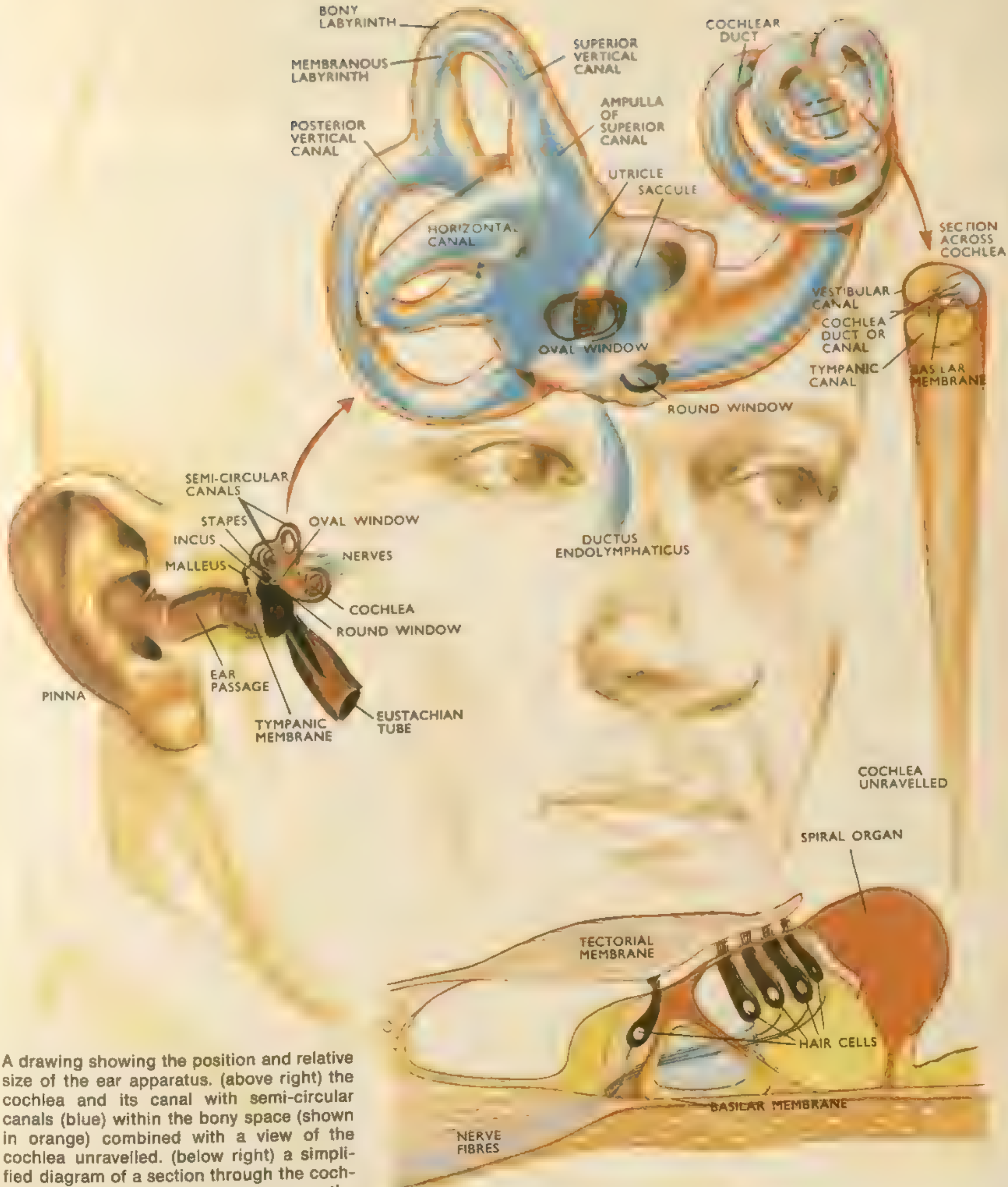
The human ear is a delicate organ parts of which are concerned with receiving sound waves and other parts which are concerned with balance—making sure we are the right way up.

Sound waves are collected by the ear flap *(pinna)* and pass down the ear passage to the ear drum *(tympanic membrane)*. This taut structure separates the outer ear from the middle ear—an air-filled cavity containing the chain of ear bones. These are the hammer *(malleus)*, anvil *(incus)* and stirrup *(stapes)*. The malleus is attached to the ear drum, which is made to vibrate by the sound waves. The movement of the ear drum is carried across the middle ear by the rocking of the ear bones, to the *oval window*, a membrane stretched across a hole in the bone surrounding the middle ear. Beyond the oval window, to which the stapes is attached, is the inner ear. This consists of a series of spaces, full of fluid, inside which is a closed system of sacs and canals also filled with fluid. The part of the inner ear that is concerned with hearing is a long coiled tube (the *cochlea*) looking somewhat like a musical horn. When the oval window vibrates to-and-fro, because the stapes is pushing and pulling on it, the pressure is transmitted through the fluid within the cochlea and affects tiny, sensitive hairs that link up with nerve fibres. The movement of these hairs results in nerve impulses being sent along the nerve fibres to the brain. In the brain these impulses are translated as sound. The ear itself does not hear: it is merely an organ for receiving sound signals and passing them as nerve signals to the brain.

A section through the human ear showing the path of sound waves from the outer ear into the cochlea.

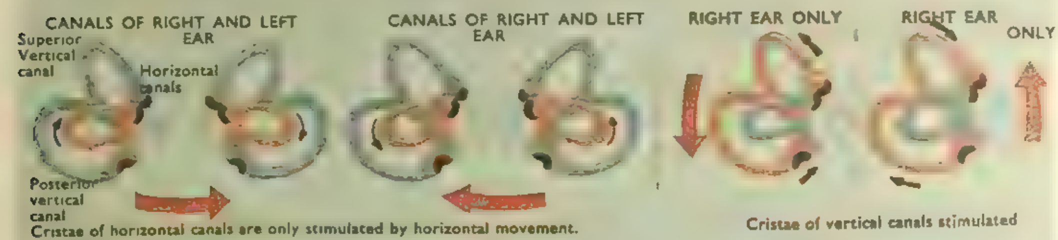


If the cochlea is straightened out it can be seen as a tapered tube containing three fluid-filled canals, the outer two of which communicate with each other by way of an opening in the apex. The oval window closes the end of the upper canal and the round window the lower canal. When the oval window is pushed inwards by the stapes, therefore, the pressure wave that is transmitted through the fluid causes the round window to bulge outwards. The two outer canals are separated from each other by a band of tissue, the *spiral lamina*, which contains the sensitive hair cells attached to the *basilar membrane*. The 'judgement' of pitch is thought to be due to the structure of this membrane. Along its length and arranged across it are a number of fibres, the lengths of which increase as the bore of the cochlea gets smaller. If a vibrating tuning fork is placed on a piano frame, one string will vibrate strongly in sympathy. In the same way pressure changes produced in the cochlea by a particular sound wave cause a particular part of the basilar membrane to vibrate. Only the hair cells of this region are

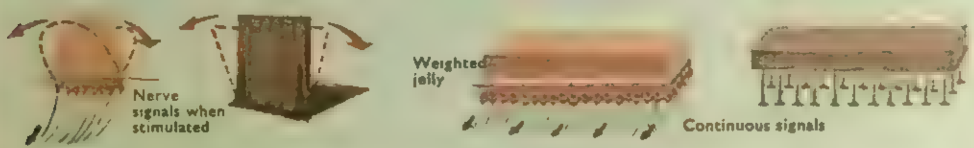


A drawing showing the position and relative size of the ear apparatus. (above right) the cochlea and its canal with semi-circular canals (blue) within the bony space (shown in orange) combined with a view of the cochlea unravelled. (below right) a simplified diagram of a section through the cochlea showing the sensitive structures on the basilar membrane.

Movements of the head (red arrows) cause the fluid to move (black arrows) in the semicircular canals. Each cupula swings, like a door that has been pushed, stimulating the hair cells. Sensory areas are shown black; the canals are viewed from in front.



The cupula moves to and fro like a hinged flap of wood when it is pushed by the fluid (right). Signals pass continuously along the nerve fibres from the maculae because the weighted jelly continually pushes on the hair cells



stimulated and so only nerve fibres from that region carry signals to the brain. It has been shown by experiment that the first coil of the cochlea contains sensitive cells that respond to high frequency sounds (e.g. 8,000 cycles per second), the second coil to medium frequencies (1,000 cycles per second), and the third coil to low frequencies (e.g. 500 cycles/second).

The middle ear, which contains air, is in communication with the back of the throat by way of the *eustachian tube.* Most of the time this is closed by a small muscle but, when we swallow or cough, the tube opens to admit air to the middle ear from the throat. This mechanism ensures that equal pressures are maintained on each side of the ear drum.

The ear drum is protected from very loud sounds by the action of two muscles, one attached to the ear drum and the other to the stapes. When these muscles shorten, the ear drum and the oval window (to which the stapes is attached) become more taut so that the extent of their to-and-fro movement is reduced.

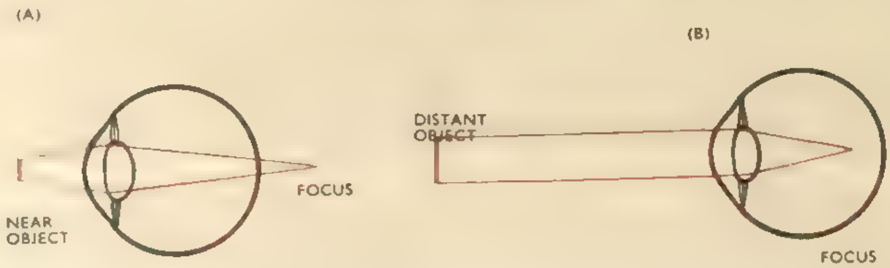
The parts of the inner ear, other than the cochlea, are concerned with balance. The principal parts of the inner ear apparatus are three *semicircular canals* leading off a large sac, the *utricle.* At one end of each canal is a swelling within which is a ridge of sensory and supporting cells—the *crista.* Hairs on the sensory cells project into a jelly-like mass and when the head is turned, movement of the fluid within the canals pushes against the jelly, moving it to-and-fro like a hinged door, so stimulating the hair cells. Signals pass from them by way of nerve fibres to the brain, and also to the eye, neck and limb muscles which help to make amends for the head movements. The three semicircular canals are arranged at right angles to each other in three planes so that movement in any direction stimulates one or more of the cristae at any one time.

The utricle and the chamber next to it *(saccule)* in communication with the cochlea also have sensitive structures *(maculae)* within them. The hairs of these are embedded in a flat mass of jelly which contains particles of chalk. They weigh the jelly down so that it is in firm contact with the hair cells. The maculae are on a side wall of the saccule and utricle but are at right angles to each other so that each position of the head affects the hair cells in different ways.

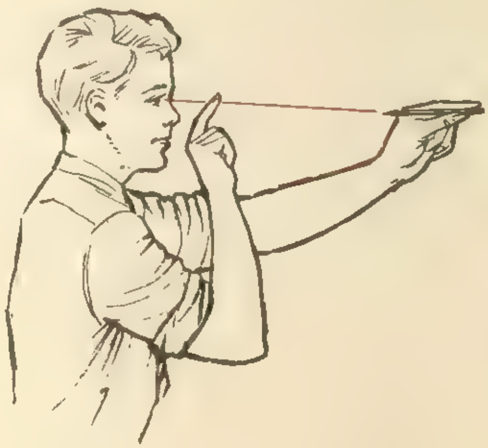
Besides the inner ear apparatus, nerve endings, wrapped round fibres in the neck muscles, leg and toe muscles, are receptive to changes in the tension of the muscles and pass signals to the central nervous system and back out to muscles so that changes in the body's position are automatically compensated for.

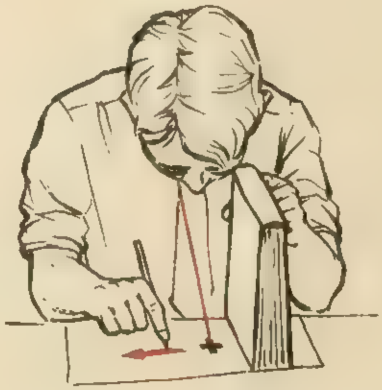
The balance of the body is maintained therefore by means of a complicated signalling system, much of which is automatic. But the brain is informed of changes concerning the rest of the body and so is able to decide what the limbs or any other part will do.

PRACTICAL PROBLEMS



1. What shape must lens become for eye to focus in (a) and (b) or what type of spectacle lens could be used? What would be the condition of the ciliary muscles and suspensory ligament at focus in (a) and (b)?





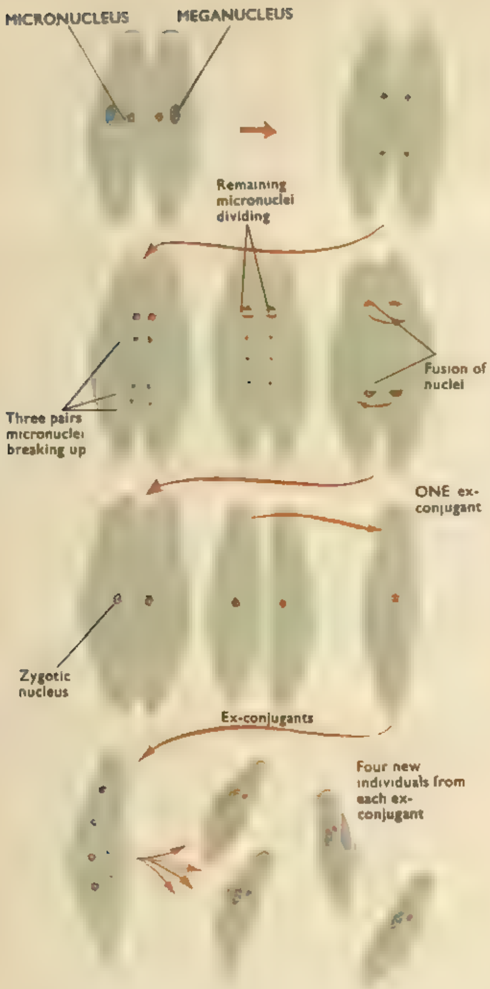
2. Hold one arm out straight in front holding pencil point facing you. Move other arm with finger outstretched towards pencil point quickly. Do this first with left eye closed, then right eye closed and then both eyes open. What difference is there in your results and why?

3. Look at cross with right eye. Move pencil away from cross in all directions marking where pencil point disappears.
   In this way you map out the area of light from the paper falling on the blind spot.

4. (a) Blindfold subject. Place a ticking watch in various positions equal distances from two ears. How accurate is subject in guessing where watch is?
   (b) Now plug each ear in turn and repeat.

5. Test sensitivity of several subjects to a ticking watch. Plot a histogram of given distance intervals at which watch can just be heard against number of people within each distance band.

Reproduction



Paramecium has two nuclei, a large *mega*nucleus and a small *micro*nucleus. When two paramecia come together (each is termed a *conjugant*) the meganucleus of each disintegrates and each micronucleus divides twice forming four micronuclei. Three disintegrate whilst the fourth divides into two. One of each pair of nuclei so produced then moves from the one conjugant into the other, fusing with the other member of the pair to form what is called a *zygotic* nucleus. The conjugants then separate and by a series of divisions of nucleus and protoplasm several new individuals are produced from each exconjugant. The number varies with different species of *Paramecium*. In *P. caudatum* eight new individuals are produced from each pair of exconjugants.

Reproduction in Animals

A FEMALE frog lays her eggs in water. They are *fertilized* by sperms from a male frog. Each fertilized egg cell or *zygote* develops into a tadpole which hatches out several days later. The young tadpoles grow up or mature, live for a time as adults (age), and eventually die. Such a pattern of development is characteristic of most many-celled animals. A young animal grows from the egg, it matures, ages, and dies. Once mature, an animal is able to reproduce and so create new individuals which, in turn, will themselves reproduce. If reproduction did not occur then the species would fail to survive. Reproduction, therefore, is essential for the continued existence of a species.

Amoeba *grows until it reaches a certain size, and then the nucleus divides into two, followed by a division of the cytoplasm into two as the nuclei move apart.*

The process of ageing is a puzzling phenomenon. Many individuals fall victim to predators, but 'natural death' appears to await living systems that are not re-arranged at intervals. An *Amoeba*, for example, reproduces mainly by a process of division or *binary fission*—splitting into two. No *Amoeba* is able to go on growing and living indefinitely without dividing. The changes that take place prior to and during the division of its nucleus and protoplasm

Paramecium also reproduces by binary fission, both micro- and meganucleus dividing into two, followed by a splitting of the cytoplasm.

Hydra reproduces by both sexual and asexual means. The asexual process is one of *budding* which takes place chiefly during the summer when food is abundant.

The body wall at one point grows rapidly forming a hollow bulge. This gradually assumes the form of a miniature adult, growing tentacles in the centre of which a mouth forms. Eventually the continuous cavity between the bud and the parent is partitioned off and the bud breaks free to assume an independent existence.

appear essential for the continued existence of a line of individuals, and ultimately for that of the species.

Perhaps the nucleus of an *Amoeba* is able to control only a certain quantity of protoplasm. When it has reached a certain size, the duplication of the other nuclear material, and the consequent sharing of the 'parent' protoplasm, enables each 'daughter' nucleus to reorganize and build more protoplasm.

Growth in many-celled animals takes place mainly by the division of cells as in *Amoeba*. Reproduction, in most, occurs through the union of sex cells or *gametes*, however. All that survives of an individual are the egg cells or sperm cells which fuse to produce new individuals. The body of the animal ages and dies.

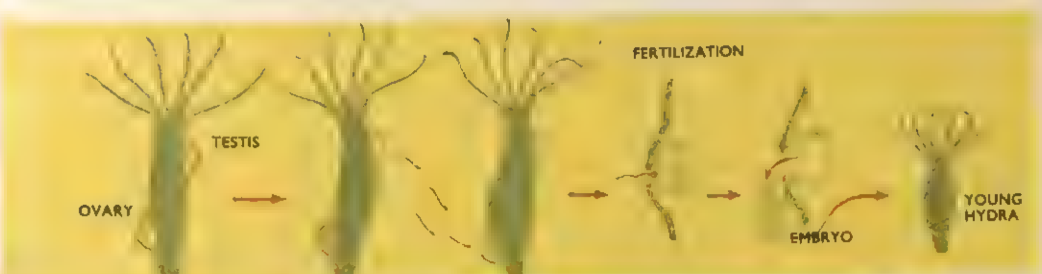
Reproduction involving sex cells is said to be *sexual*. It is characteristic of higher animals. Both *asexual reproduction* (without gametes) and sexual reproduction occur in many lower invertebrates (e.g. coelenterates). In the lower many-celled animals, such as *Hydra*, the protoplasm of many of the body cells seems to retain the capacity for growth and reorganisation. Eventually they form a new adult. In higher animals, only the sex cells retain this ability, the ordinary body cells cannot grow into new individuals.

Sexual reproduction occurs in many protozoa. Two individuals may pair *(conjugate)* and exchange nuclear material. Alternatively, parts of individuals, formed by separation of buds or by the division of the adult nucleus and protoplasm, may pair. Usually the male and female halves of each pairing are formed by different parents.

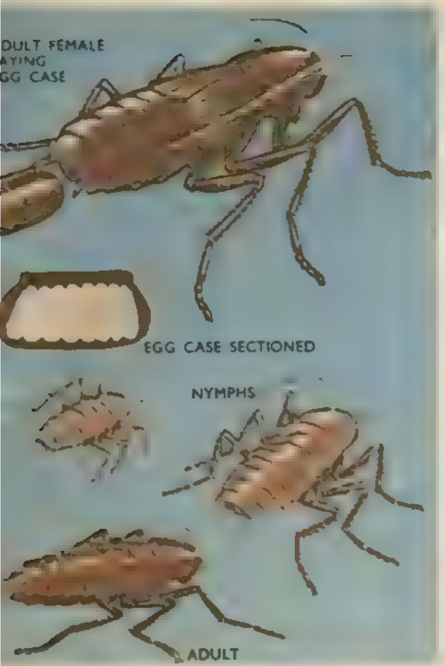
In some insects (especially greenfly) and roundworms one or more generations may be produced by the development of eggs that have not been fertilized. This is called *parthenogenesis*.

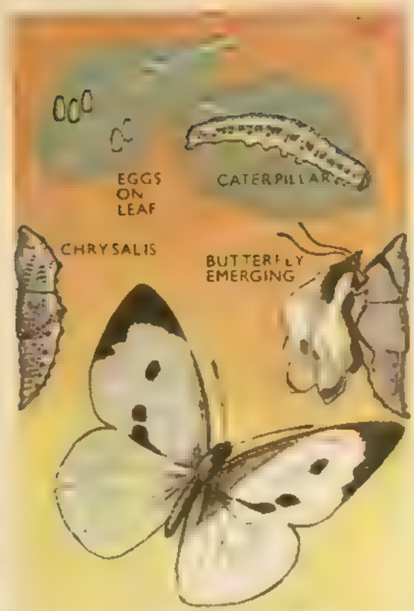
Occasionally the young stage of an animal becomes sexually mature and reproduces, a phenomenon known as *neoteny*. This occurs in a Mexican newt, *Ambystoma*, for example.

Most fishes lay eggs, some in incredible numbers. A female cod may contain as many as nine million and halibut more than two million. The chances of an egg or of a young fish surviving are



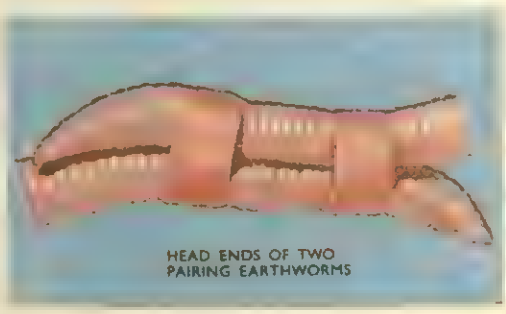
Both male structures (testes) and female structures (ovaries) develop on the same individual. *Hydra* is said to be *hermaphrodite*, therefore. Usually the testes mature first so that one of the male cells fertilizes the egg of another *Hydra*. The male cells or sperms are released into the water and swim to the egg cell in the ovary. Fusion takes place and the fertilized egg or *zygote* divides many times to form an *embryo*. This is released, and falls to the pond floor. In suitable conditions the protective coat round the embryo ruptures and the young *Hydra* emerges.





(centre) A caterpillar or *larva* hatches from a butterfly egg. The caterpillar eats and grows rapidly before changing into a resting, non-eating stage, called a chrysalis or *pupa*. From the chrysalis the adult butterfly emerges. In such a life history the development from egg to adult takes place by way of distinct changes of form. Each change is called a *metamorphosis*. (left) In some insects the development is more gradual than that of the butterfly. The cockroach, for example, when it hatches from the egg, is like a miniature adult, except that it has no wings or reproductive organs. As it grows in size it matures until it becomes a complete adult. (right) In many coelenterates (e.g. *Obelia*) budding results in the formation of a colony, for the buds do not separate. The individual animals (*polyps*) are of two types, feeding polyps and reproductive polyps. The latter produce jellyfish-like buds or *medusae*. These swim in the sea after separating from the polyps. Each medusa produces either male or female cells. These are released into the sea where fertilization takes place. The fertilized eggs develop into a hairy or ciliated larva called a *planula*, which later rests on the bottom and develops a mouth with tentacles round it. By budding, a new colony is produced.

The earthworm is hermaphrodite but, in order to produce young, two earthworms have to come together. Each lays a batch of eggs which are fertilized by the other worm. Pairing is a complicated process designed to obtain transfer of male cells from each worm to the other without self-fertilization taking place. After male cells have been exchanged the worms separate. The worm's noticeable pink band or *clitellum* produces at intervals a number of slimy *cocoons* into which the eggs pass. As the cocoons slide forward towards the head of the worm, male cells are released into them and fertilization takes place. The cocoons fall into the soil. In *Lumbricus* (the common earthworm) only one egg develops in each cocoon.



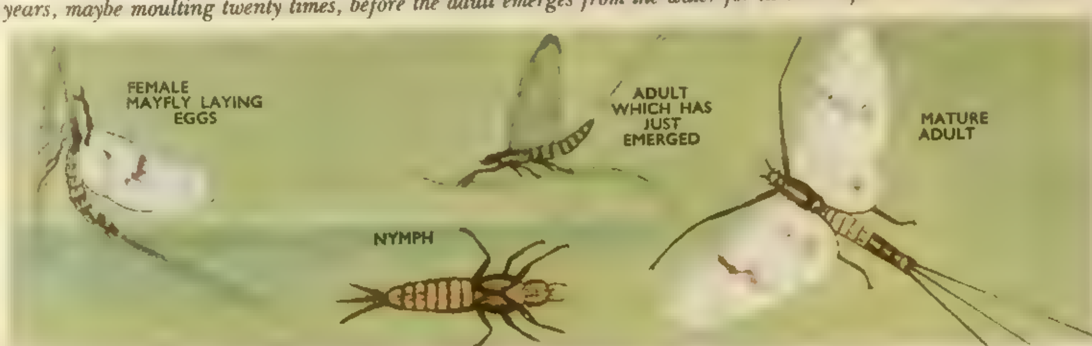
HEAD ENDS OF TWO PAIRING EARTHWORMS

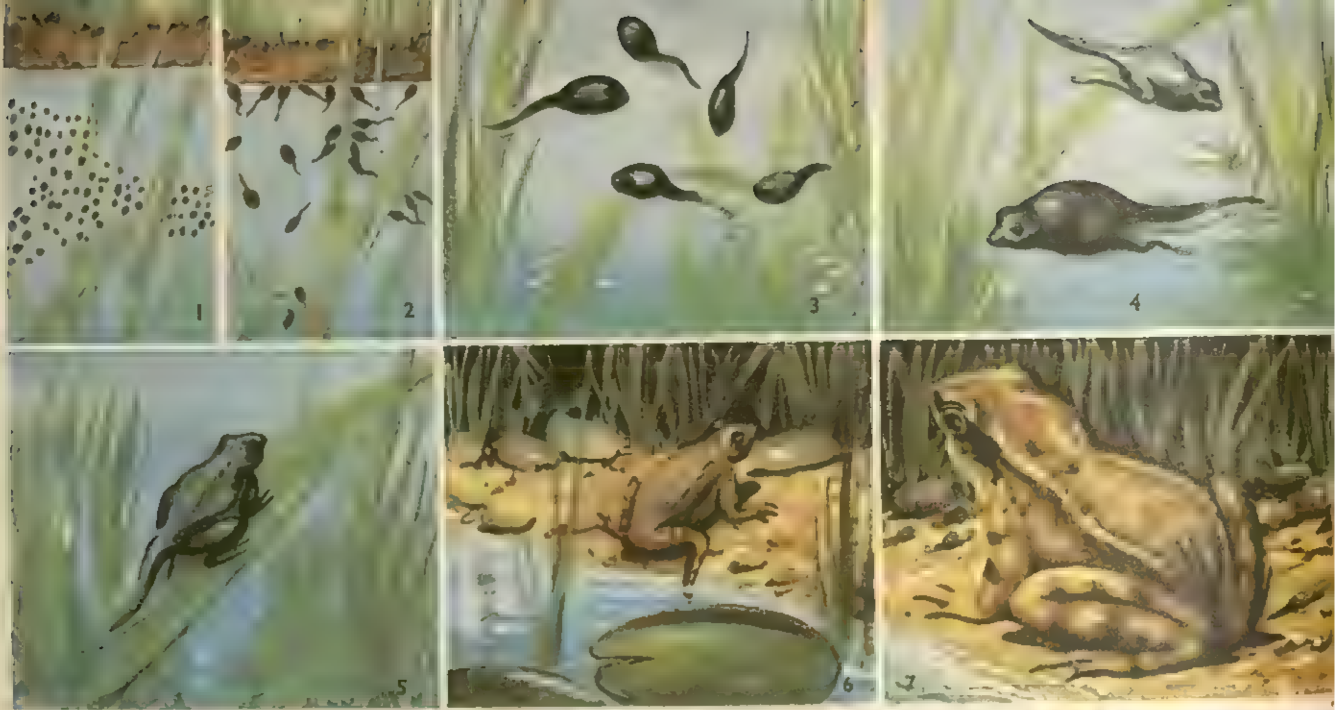
(top) The red cheeked salamander of North America lives on land. The eggs hatch directly into miniature adults. (bottom) The midwife toad lays a string of eggs which are then wrapped round the legs of the male until they are ready to hatch. (middle) The mud puppy retains its larval characters throughout life. It lives in water and lays eggs from which young individuals emerge.

very low, however. Many are not fertilized, and both eggs and young fall victim to predators. Few adult fish care for their young. Those that do generally lay far fewer eggs. Sticklebacks lay from fifty to a hundred eggs which are zealously guarded by the male. Some sharks and a few bony fish bear their young alive. Many shark-like fishes (e.g. dogfish and most rays and skates) produce large horny egg cases—so-called Mermaid's purses. The purses are laid in water and become attached to seaweeds and other objects by means of long filaments.

Though the majority of amphibians live on land, they are not fully terrestrial and most have to return to water to breed. The eggs of newts and salamanders are fertilized within the body of the female. They may be laid singly or in large groups. Like frog's eggs they have a sticky covering which swells up when they are laid in the water. Tadpoles hatch from the eggs and gradually obtain adult features. There are variations from this typical life history. Some salamanders give birth to live young. In most frogs and toads spawning takes place in water and the eggs are usually fertilized as they are being laid or just after. The Midwife toad, found in southern Europe, pairs on land. The eggs, laid in strings, are then wrapped around the legs of the male toad. The tadpoles develop within two or three weeks and hatch when the male lays them in water. The eggs of amphibians are soft and jelly-like, lack a supporting shell, and the young are usually only able to survive in water. But reptiles are fully terrestrial; to such an extent that water dwellers, such as turtles, have to return to land to breed! Most reptiles lay eggs, some give birth

The female mayfly lays eggs in water. Each hatches into a nymph which is adapted for living in water. The nymph grows for up to three years, maybe moulting twenty times, before the adult emerges from the water for its short life.





Frog life cycle. 1. Frog's spawn in a pond. 2. The tadpoles, which soon hatch, breathe first by external gills. 3. External gills replaced by internal gills. 4. Hind legs appear later followed, 5, by front legs. 6. The tail has almost disappeared and the miniature frog leaves the water. 7. Fully grown frog.

to live young, and a few retain the eggs within their bodies until they are ready to hatch. Reptile eggs show several advances on those of amphibians. The soft substance of the egg is surrounded by a tough, leathery shell which provides the support that a living structure needs on land and also restricts water loss to the atmosphere. The eggs have large quantities of yolk to nourish the developing young and a special sac, the *allantois*, enables oxygen and carbon dioxide to pass between the embryo and the outside world. Each embryo develops within a fluid-filled sac or *amniotic cavity*, the equivalent of the frog tadpole's pond.

In birds the egg shell is tough and brittle and though each egg contains a rich supply of yolk the proportion is not so high as in reptiles—development is usually shorter. Birds, like mammals, are warm-blooded and the developing egg must be kept warm. Parental care reaches an extremely high level. Many birds build very elaborate nests in which to incubate the eggs and bring up their young. Adult birds spend a large part of each day collecting insects and other food.

Mammals give birth to live young (except the platypus and echidnas) and suckle them on milk produced by special mammary glands.

In the fertilized egg the chick embryo develops as a disc of cells on top of the yolk from which it derives nourishment. Gradually the various organs of the chick appear, its brain, backbone, eyes, beak, etc., until the yolk is used up so that just prior to hatching the chick almost fills the egg.

In general features the pig embryo resembles that of the chick in its early development. The egg is tiny, however, and contains only a small amount of yolk. The embryo is nourished by the blood of the mother within whose body it develops.

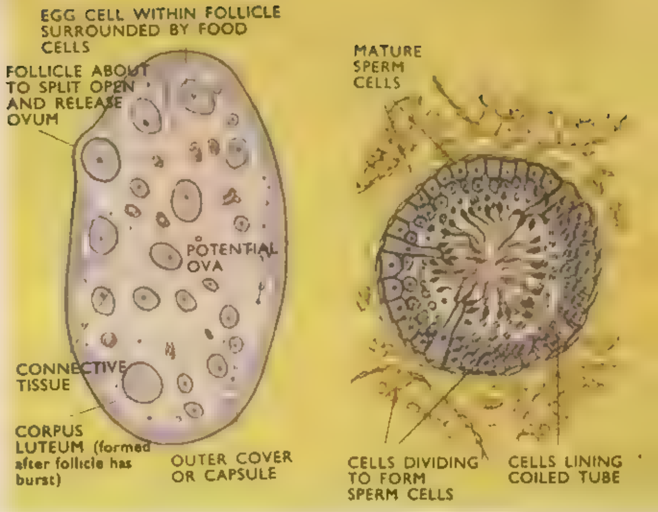
Reproduction in Man

In Man, as in the majority of mammals, the reproductive system is developed for fertilization of the egg within the body of the female and for its prolonged development there. An elaborate organ, the *placenta*, is provided for the protection and nourishment of the young during their stay in the womb or *uterus*. The placenta is formed by the fusion of part of the embryo and the lining of the uterus. As the embryo grows its connections with the lining of the uterus become more and more intimate. Gradually the layers of tissue between the blood vessels of the embryo or *foetus* and those of the mother are 'eaten' away by the action of enzymes until eventually only the walls of the foetal blood vessels and a little of the mother's connective tissue keep the foetal blood separate from that of the mother. Because the barrier between the two is so small the exchange of food, oxygen and waste between mother and child can be extremely rapid and efficient.

The reproductive system of man is similar to that of other placental mammals (see illustrations). The paired organs of the male—*testes*—that produce sperms consist of masses of tiny coiled tubes.

In Man as in other mammals fertilization takes place inside the female reproductive apparatus. Sperms are introduced into the uterus via the penis, which is tubular, in a fluid called semen. (Experiments performed with filtered frog semen proved beyond doubt to early investigators that the sperms held back by the filter were responsible for initiating the development of eggs. If the filtrate was added to the material held back by the filter and then mixed with unmated frog's eggs the eggs developed.)

Usually only one sperm cell penetrates an egg cell but, to ensure fertilization, a large number are produced. Fertilization occurs high up in the egg ducts (*fallopian tubes*) and the fertilized egg starts to divide as it passes down towards the uterus. Prior to fertilization, as the egg develops in the ovary, the womb is prepared to receive a fertilized egg. Its

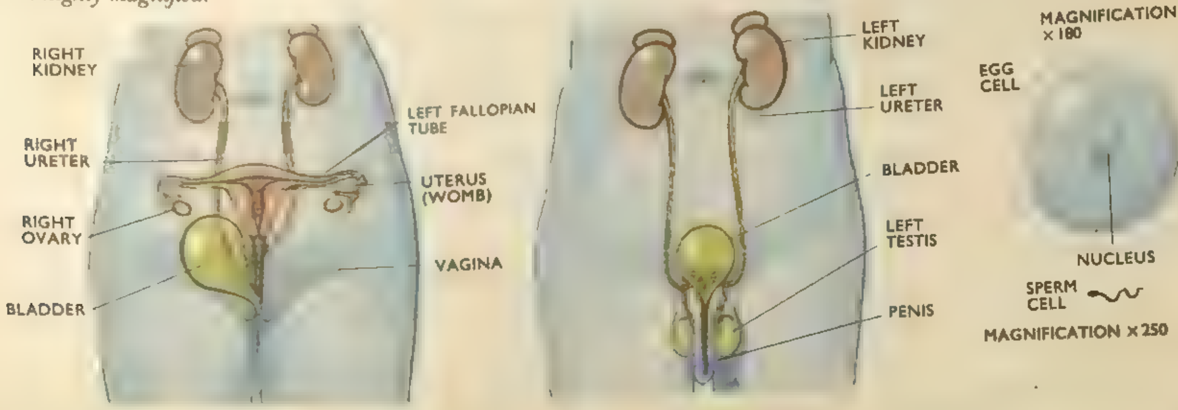


(left) A section through a human ovary. (right) Each human testis consists of masses of tiny coiled tubes. Diagram shows one tube in cross-section.

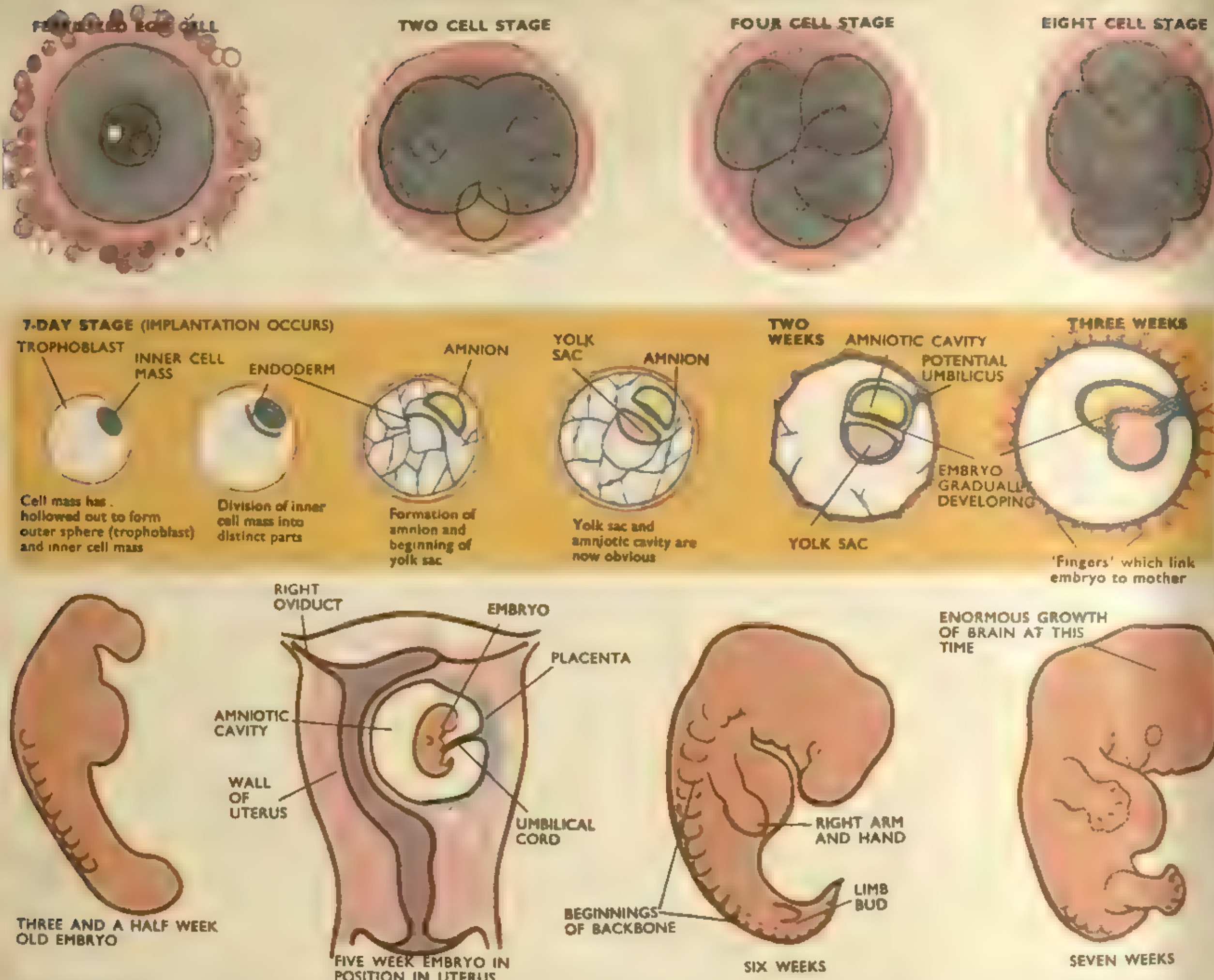
lining thickens, becomes more muscular, and richer in glands and blood vessels. In fact the uterus lining continues to thicken for a while—after the egg has been released from the ovary—whether fertilization occurs or not. If fertilization does not occur the growth of tissue continues for a further fourteen days. It then breaks down and erodes away with the loss of blood characteristic of *menstruation*. Growth of the uterus lining and subsequent menstruation take place regularly during approximately 28-day cycles. There is great variation between individuals, from 24 to 35 days. The first flow of blood *(menses)* occurs at an age of about 12 to 16 years—earlier in some instances—and proceeds up to the age of 45 to 50 or just over. It is interrupted by successful fertilization if the fertilized egg is accepted by the uterus.

By the time that the tiny fertilized egg or *zygote*, which contains the complete instructions for producing a new individual and for controlling its later life, has reached the uterus it has divided several times. It becomes embedded or *implanted* in the uterus lining about seven days after fertilization.

(left and centre) The reproductive system of the human female and the human male simplified. (right) A human sperm and an ovum highly magnified.



THE DEVELOPMENT OF A HUMAN FERTILIZED EGG CELL



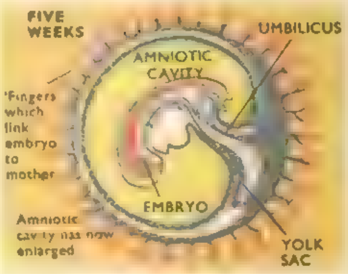
After fertilization, the tiny fertilized egg or zygote divides several times before it reaches the womb. It is a gooseberry-like cell mass. Implantation, the establishment of the zygote in the wall of the womb, occurs after about 7 days. Gradually, the features of the embryo become clear. At 3½ weeks the body segments are clearly visible and the limb buds are beginning to appear. After about 5 weeks the umbilicus is established between the embryo and the placenta. At 6 weeks the arm and hand buds are clearly developed, beginnings of the backbone can clearly be seen and the hind limb buds appear. At 7 weeks first details of the toes and fingers can be seen. By 12 weeks the foetus is almost a miniature version in external features of what it will be at full term (9 months). The main changes take place within the body of the growing child in the remaining 6 months.

The lining continues to grow, especially its blood vessels, so that, once the small supply of yolk in the egg has been used up, it receives nourishment quickly from the mother's blood.

The fertilized egg cell first divides into two cells, then four, eight and so on, to form a ball of cells, which hollows out with a small band of cells within. Most of the latter grows into the foetus and part of it together with the outer sphere of cells fuses with the uterus lining to form the placenta. Gradually the structure of the embryo becomes more obvious and the *umbilical cord* through which food, oxygen and waste are exchanged is formed. A fluid-filled sac surrounding the growing foetus protects it during its development.

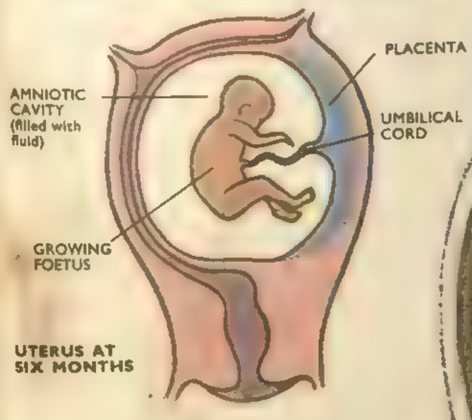
The period that the embryo spends developing within the womb (called *gestation*) is about two hundred and eighty days in man. The placenta protects and nourishes the embryo for the whole of this time. At birth the young child is expelled from the womb by the automatic contractions of the muscle in its walls, and usually also by the co-ordinated action of the mother. Following birth the umbilicus still connects the child to the placenta. It is ligatured (tied) and cut, and from that moment the child is, in many respects, on its own. The lungs must function – the infant can no longer rely on a supply of oxygen through the umbilicus. Similarly it must take in and digest food itself, get rid of waste and so on.

BALL OF MANY CELLS



EIGHT WEEKS

TWELVE WEEKS



UTERUS AT SIX MONTHS

(right) A fully developed foetus within the uterus or womb of the mother. The space below the head represents the amnion which ruptures during the birth process releasing the amniotic fluid.

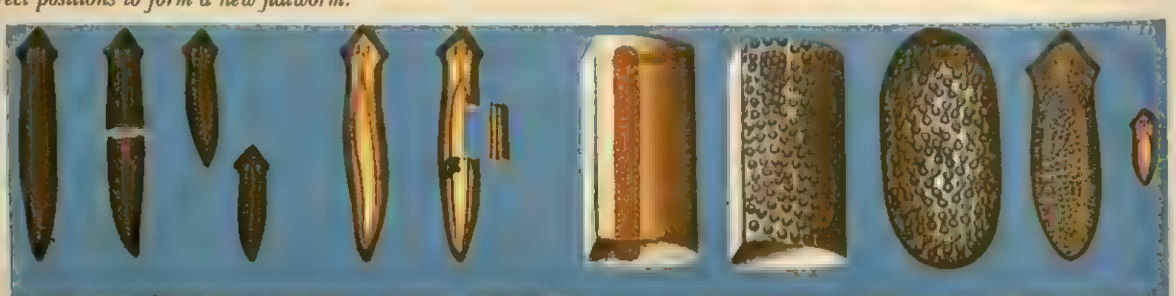
Crabs are able to break off their limbs at a particular point (shown arrowed in the inset) in order to escape from enemies. New limbs will grow and become fully formed after one or more moults.

Regeneration

By reproducing an animal creates other individuals and so ensures that the species continues to exist. Though each individual cannot go on living for ever, the ability to replace or repair lost or damaged parts (called *regeneration*) plays an important part in prolonging its life. All animals and plants are able to regenerate to some extent, but as a general rule, the more highly evolved an animal is the less are its powers of regeneration. Man, for example, is able to regenerate skin and bone tissues, to mend wounds and fractures, but is unable to grow even a finger if one should be lost. Some damaged internal organs can be regenerated if a large enough part remains; the liver is an example of this. The replacement of worn-out tissues is a form of regeneration and goes on throughout life.

In the lower animals the powers of regeneration are very great. Best known are the flatworms, an individual of which can be cut up into a number of pieces all of which can grow into whole individuals providing the pieces are above a certain minimum size. Some animals are able to shed limbs in order to escape (called *autotomy*). The limb breaks at a particular point and a new one will grow and become fully formed after one or more moults. A lizard is able to shed its tail, leaving it wriggling on the ground in order to confuse an enemy.

If a flatworm is cut in half each piece will re-grow. The front quickly grows a tail but the tail has to form a head before forming the missing organs. A whole new flatworm can regenerate from a tiny portion provided that skin and gut cells are present. The enlarged drawing shows what happens to the flatworm's segments as it is reorganised to form a tiny flatworm the size of the fragment. Gut and skin cells become unspecialised. Then these divide and re-divide, and eventually take on special tasks when they are sorted into their correct positions to form a new flatworm.



4. Plant Physiology

The Root

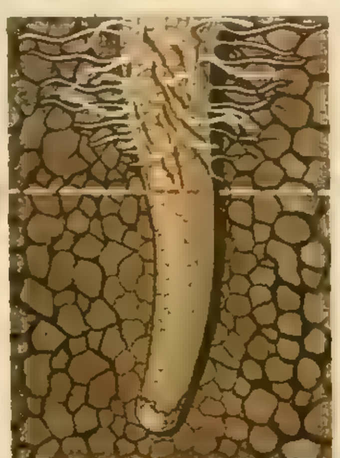
PLANTS, unlike the majority of animals, remain fixed in one place absorbing food from their environment. Roots play an important role in this way of life. They serve as organs of attachment, anchoring the plant in the ground, and also as organs of absorption and transport for water and dissolved salts. These are the major functions of roots.

Normally, roots grow downwards under the influence of gravity and away from light. This reaction enables a sprouting seed to get a hold on the soil. There are two basic patterns of root growth—the *tap-root* system (e.g. thistle) and the *fibrous* system found, for example, in grasses. The tap-root system is an extension of the primary root *(radicle)* of the young seedling, but in fibrous systems this primary root is quickly replaced by numerous fine roots from the base of the stem. All roots which do not grow from the primary root (e.g. the roots on a rhizome) are called *adventitious*. Propagation of plants by cuttings relies on the development of adventitious roots on the stem.

Root Structure

At the tip of all roots there is a mass of cells—the *root-cap*—which protects the growing point during its passage through the soil. The cells of the root-cap are produced by the actively dividing cells of the growing point. As the outer parts of the root-cap wear away, fresh cells replace them. The old cap may also lubricate the tip as it grows downwards. Cells formed just behind the tip lengthen rapidly and push the tip further into the soil with considerable force. The growing region is followed by the *root-hair* region. The hairs are outgrowths of the *exodermis* and are the main organs of absorption. They penetrate the soil and absorb water. The root-hairs occupy only a limited region. Hairs on the growing region would be sheared off as the root pushed downward. Each hair has only a brief existence and as the hairs die off they are replaced with new ones further down. The hair region is thus kept at a more or less constant size. Branches—if any—occur behind the root-hair region.

(left) The tap-root system of a thistle and the fibrous system of a grass. (right) An enlarged root-tip showing the cap and the region of growth. Note how the soil particles are compressed by the growth pressure of the root.



The root contains the same sort of tissues as the stem but the strengthening tissues of the root are centrally placed, reflecting the pulling strain suffered by the root as opposed to the bending strain imposed on the stem.

The root section shows two main parts, a central zone containing tubes of two basic types, and an outer zone made up of roughly egg-shaped cells. The tubes that are arranged in a rod up the centre of the root are called *xylem* tissue. The tubes arranged around the central xylem are *phloem* tubes.

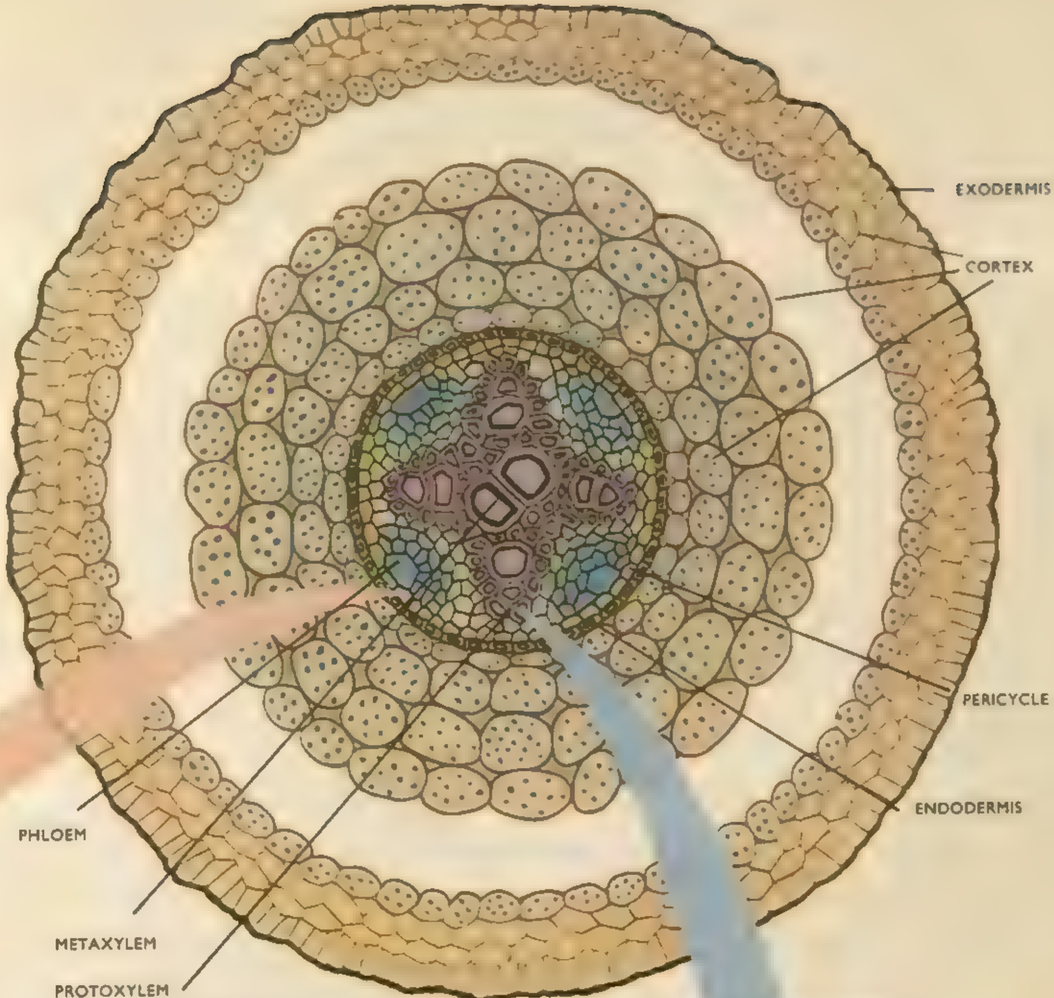
These tubes started life as fairly typical plant cells but their shape and structure changed as they developed. When they are fully developed they cannot grow or divide. Xylem tubes are really the dead remains of cells of which only the thickened walls have remained. Between the xylem and phloem tubes are columns of cells called *cambium*.

> The central portion of the root is called the *stele*. Its outer layer is the *pericycle*.

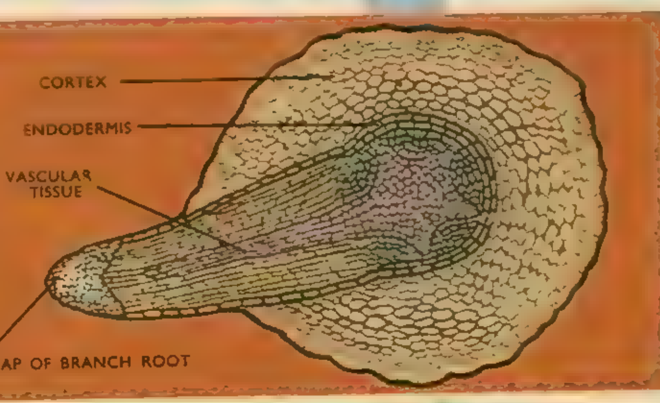
These cells are fairly typical plant cells which are able to divide and to develop into either xylem or phloem tubes. Cambium cells are responsible for the secondary growth of the root which causes it to increase in girth. A continuous wavy cylinder of cambium is thus formed. The secondary tissues are produced from this as illustrated.

Branching in the Root

In the stem, buds develop from the outer tissues close to the tip. From these, branches develop externally. Root branches develop behind the growing region internally. Branching develops before secondary thickening begins.

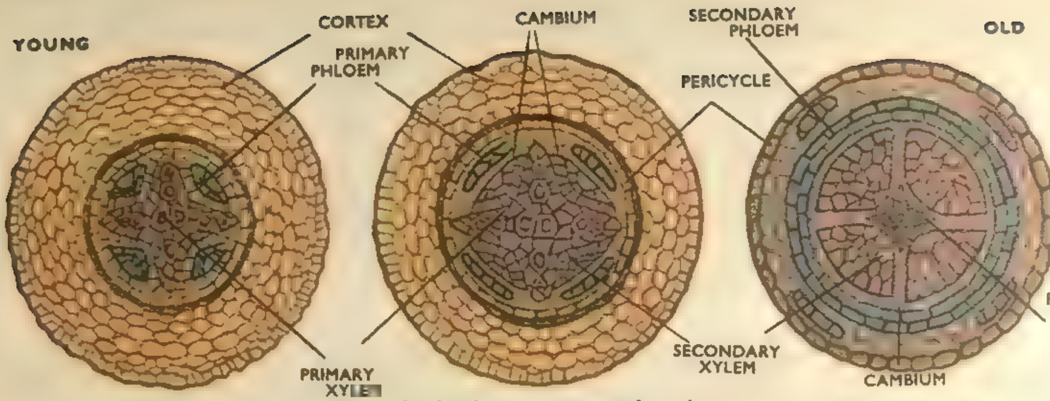


A transverse section to show the arrangement of the tissues in a young dicotyledon root.



Branch roots develop internally and grow out through the cortex. When they appear outside the parent they are behind the root-hair region.

A root branch is formed when the *protoxylem* groups become active and produce a growing point.



Stages in the development of secondary tissues.

The cells in the growing zone are at first all alike —roughly slab-shaped, with a thin cellulose wall, a nucleus and protoplasm. These cells can and do divide. Behind the growing tip the changes take-place which convert these cells into the cells and tubes of the fully developed root. When it breaks out of the parent root the vascular connections are complete and the region is behind that of the root-hairs. The degree of branching is associated with the size and habit of the plant. Large trees have thick, spreading roots for firm anchorage.

Between the root and the stem is a region called the *hypocotyl* (high-po-cot-ill). In this region the vascular tissues change from the root arrangement to that of the stem, but they are *continuous all the way through.*

Root Modifications

Very often the root is modified for storage. Roots that survive the winter contain food material (e.g. starch) which will be used by the developing shoots in spring. Man has made use of such stores in plants like carrots, turnips and beet. These are tap-roots, but adventitious roots also serve as storage organs. Dahlia 'tubers' and various orchid roots are examples. The food may be stored in the cortex or the phloem. The climbing roots of ivy are adventitious—arising all the way along the stem—so also are the roots on strawberry runners. Some tropical orchids which grow on tree trunks have spongy roots exposed to the air. The roots absorb moisture and may contain chlorophyll too. Maize plants and many others have *stilt* roots which develop from nodes on the stem and provide extra support. *Prop* roots are admirably shown in the Banyan tree. Roots develop in the horizontal branches and grow into the soil. They form solid supports for the spreading branches. Some swamp-growing plants such as the mangrove develop *breathing-roots.* The swampy soil is poor in oxygen and some root branches, which may or may not be adventitious, grow upwards into the air. Oxygen diffuses to these and into the rest of the root system.

TURNIP

DAHLIA TUBERS

STILT ROOTS OF MAIZE ARE STRENGTHENED ON THE OUTSIDE

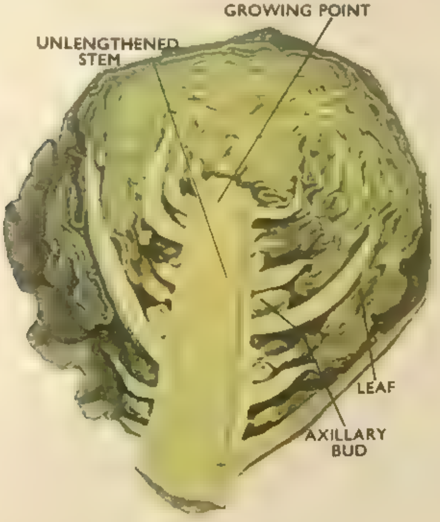
The Stem

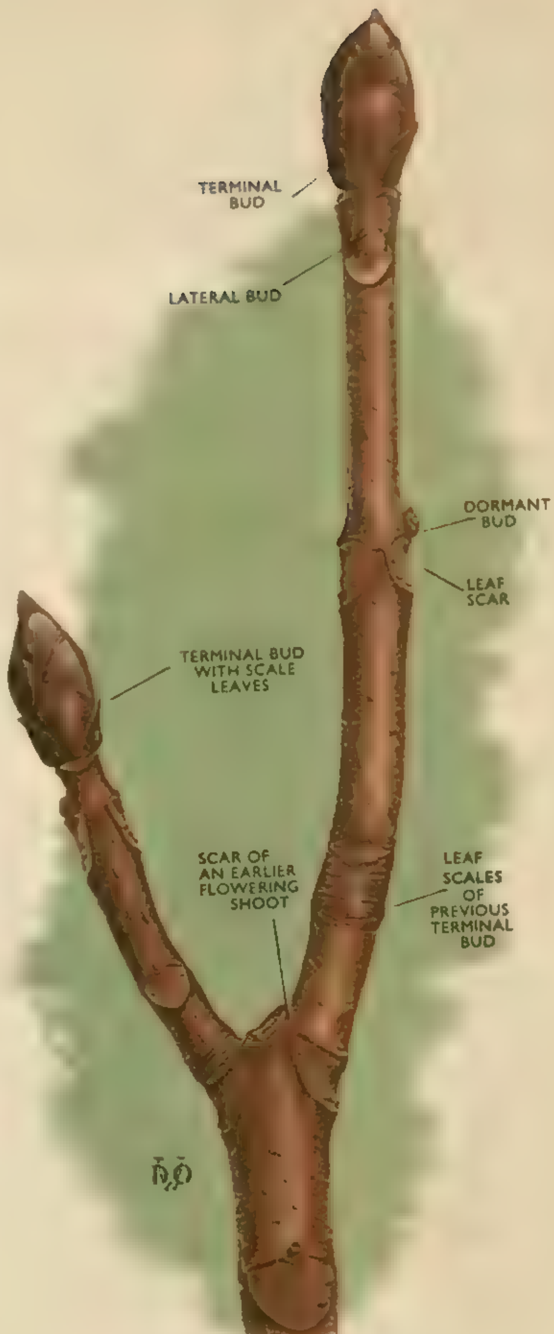
PLANT stems perform two basic functions: they support the leaves and flowers and they carry water and food from place to place within the plant. The typical stem is cylindrical and may be soft (herbaceous) or woody. It is usually branched and leafy. The point at which a leaf joins the stem is called the *node*. There are several nodes on a stem, each separated by leafless *internodes*. Each node has one or more leaves, each of which has a bud in its basal angle *(axil)*. These *axillary* buds often remain dormant but may produce a branch, especially if the main stem is damaged. Buds are in fact miniature shoots (stems) which have not yet elongated. The leaves are clustered together around the tip (the *growing point*) (see illustration). It is in winter that buds are most noticeable. The outer leaves are modified as protective scales around the young stem. When these scale-leaves fall off in spring they leave rings of scars on the stem. The age of a woody twig can be established by counting these scar patches.

Internal structure

The internal structure of the stem reflects the function. There are conducting and supporting tissues. These are basically the same in all parts of the plant and the description given here will cover roots and leaves as well. It is in the *arrangement* of the tissues that roots and stems mainly differ.

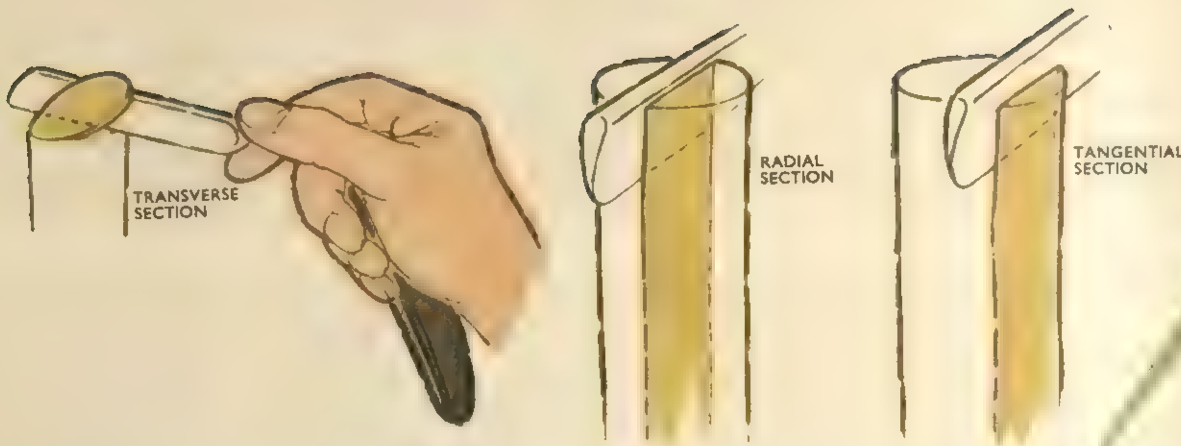
The Brussels sprout, seen here in section, is a bud, i.e. it is an unlengthened shoot. The growing point is surrounded by leaves, each of which has another smaller bud in its axil. When the sprout elongates, the region (internode) *between the leaf-bases will become longer and the shoot will assume the appearance of a normal stem.*





A horse chestnut twig in winter showing the scale leaves, leaf scars and the scar of a flowering shoot.

In order to find out how a stem is constructed thin slices are cut and examined under a microscope. To get a complete picture of the shape of the cells which make up the stem we need to look at them from one end and at least two sides. We need three kinds of sections—(a) cross-sections called



transverse sections, (b) lengthwise sections through the middle—*radial* sections, and (c) lengthwise sections to one side—*tangential*.

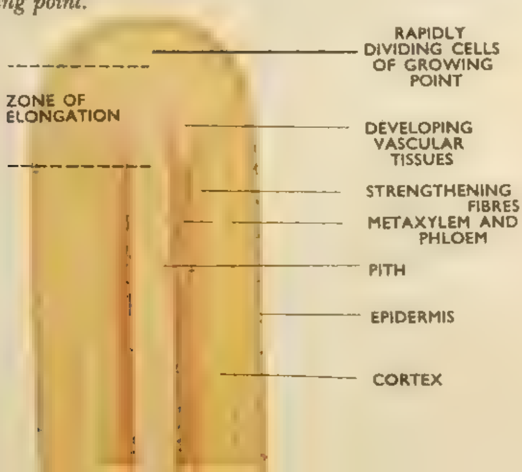
Another way of dealing with the problem is to break up the collections of cells chemically, e.g. by boiling in nitric acid and potassium chlorate. By this means suspensions of whole cells can be examined.

Cells from plant stems are seen to be broadly of five types.

(a) 'skin' cells—epidermal cells forming an outside layer. (b) 'packing' cells—more or less flattened, egg-shaped cells which form in herbaceous stems (i) a thick external layer with air spaces between the cells, and (ii) those which form a central pith. (c) Tubes of various shapes. (d) Rectangular slab-shaped cells able to divide. (e) Fibre cells.

The illustration is a summary of what we can learn by section cutting about the structure of a plant stem. The detailed arrangements of the cells differ between one kind of plant and another, and

A diagrammatic longitudinal section through a stem tip to show the differentiation of the tissues from the meristems of the growing point.



Each region between two vascular bundles is called a *ray*.

in woody plants between young and old plants. The diagram illustrates the arrangement in plants such as sunflower, nettle, buttercup—that is plants in one of the main groups of flowering plants called the dicotyledons.

The cross-section in the inset shows a ring of similar structures arranged near the outside of the stem. These are called *vascular bundles*. Each bundle consists of two sorts of tubes, xylem tubes towards the inside of the stem, phloem tubes towards the outside of the stem, with cambium cells (rectangular, slab-shaped cells able to divide) between the two types of tubes. In this stem each vascular bundle is supported by a column of fibres.

The central pith and the layers outside the ring of bundles consist of 'packing' cells called parenchyma.

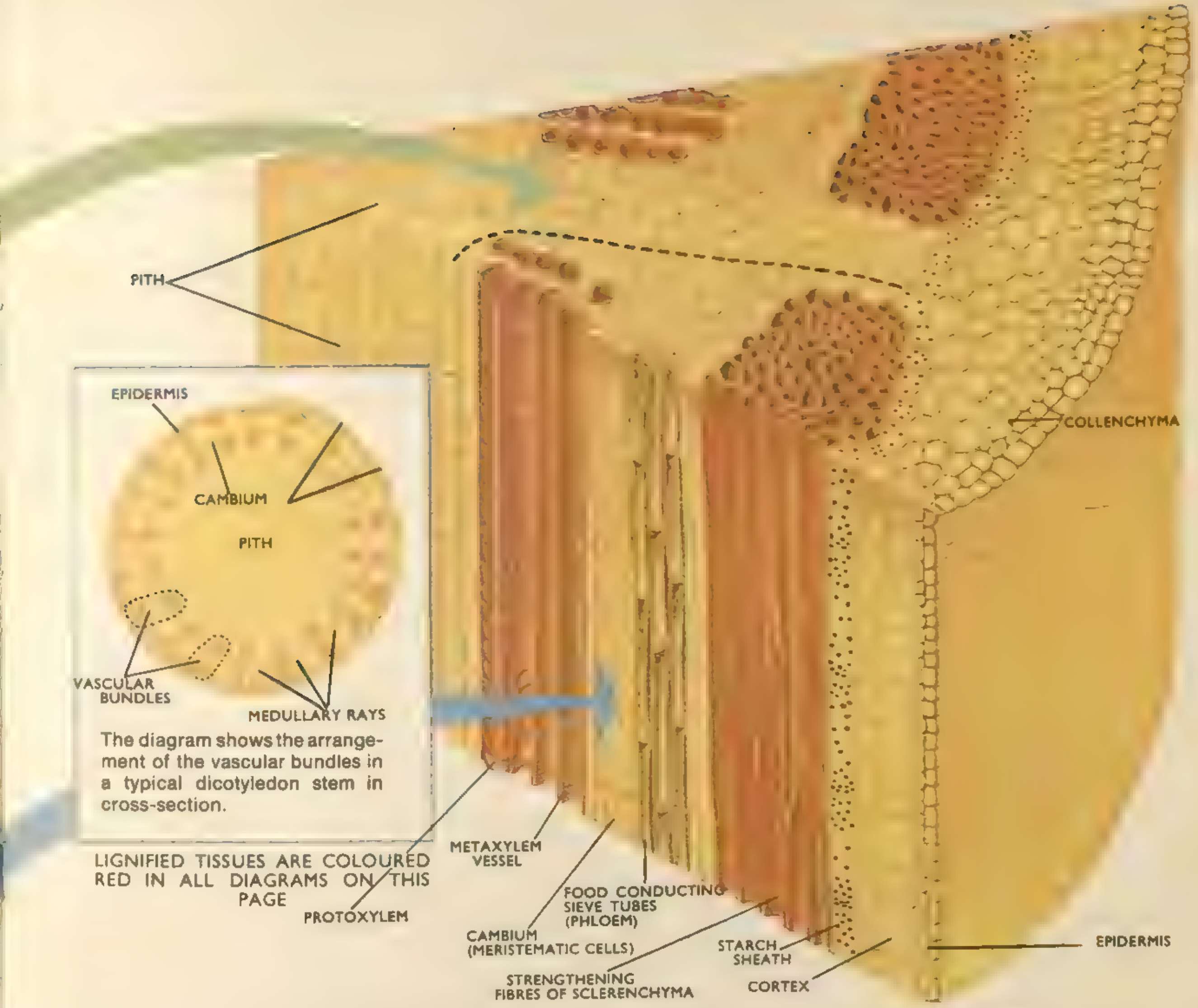
The skin on the outside surface of the stem is a continuous layer of epidermal cells, some of which have hair-like projections in some plants (page 146).

Plant growth

The growing point in a stem is situated right at the tip. It consists of rapidly dividing cells which are without vacuoles.

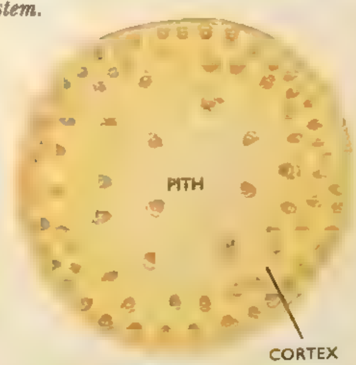
Growth takes place just behind the tip. The cells produced by the meristem develop vacuoles and lengthen rapidly, producing a lengthening of the stem. As the cells lengthen they begin to change in character *(differentiate)*.

These actively dividing cells or *meristems* of the *cambium* play an important part in secondary thickening.

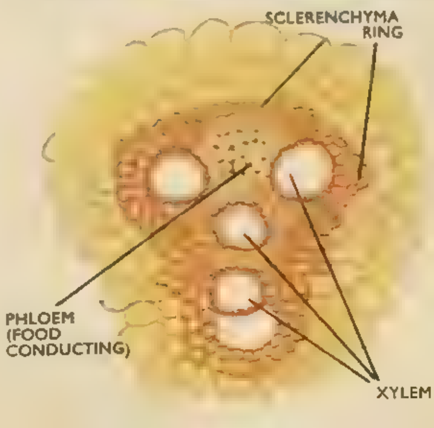


A small segment of the stem has been greatly enlarged to show the arrangement of the tissues in cross-section and in longitudinal section.

The irregular arrangement of the vascular bundles in a monocotyledon stem.



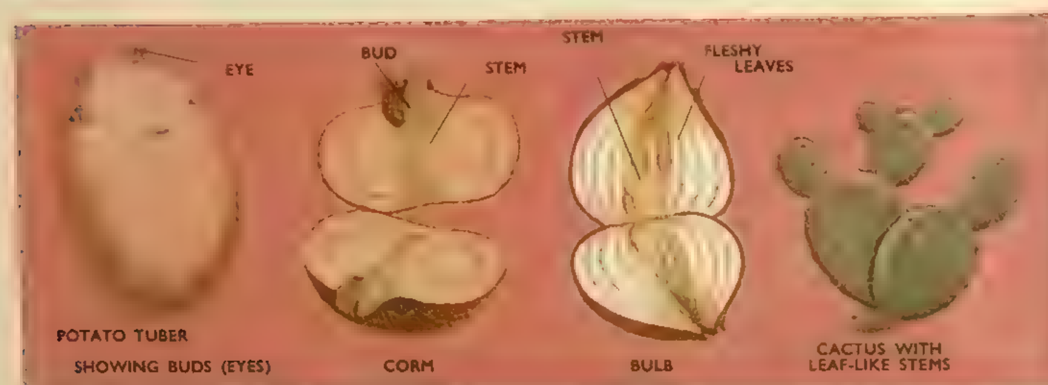
The vascular bundle of a monocotyledon (magnified).

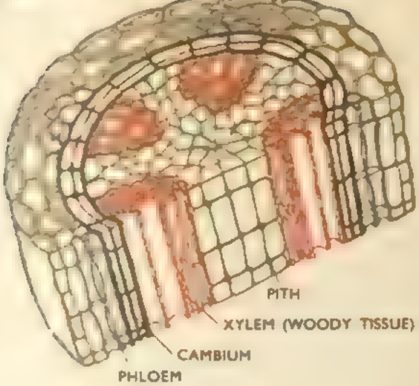


Modified stems

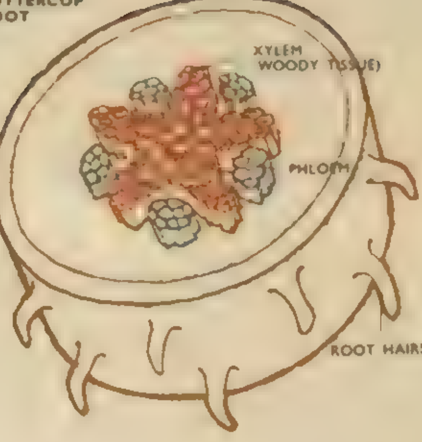
Stems frequently perform other functions in addition to or instead of their basic ones. The chief modifications are concerned with food storage and vegetative reproduction. *Runners* are long thin stems which spread over the ground surface and produce new plants some distance from the parent. Strawberries reproduce rapidly in this way. Horizontally-growing underground stems are termed *rhizomes*. They may be food stores, as in Irises, or merely reproductive shoots, as in some Grasses. Potatoes are swellings *(tubers)* arising on the underground parts of the stem. They serve as food stores and reproductive organs. These underground stems can be distinguished from roots by the presence of scale leaves and buds. *Corms* are special types of underground stems. They are swollen with food reserves and carry a number of scale leaves. One or more buds are developed in the axils of the leaves and these buds produce the flowering shoot. The base of each new shoot forms a new corm. Corms are distinct from *bulbs*. The latter are small underground stems with a number of fleshy scales in which food material is stored. In both corms and bulbs the flowering shoot is fully formed underground and grows rapidly when environmental conditions are suitable. Next year's shoot develops in the axil of one of this year's leaves.

Climbing stems are fairly common. They may climb by coiling round a support (e.g. Runner beans), by using tendrils (e.g. Vines) or by using hooked prickles to scramble over the vegetation (e.g. Blackberry). Protective spines often occur as stem modifications (Hawthorn) or as stem outgrowths (Rose). Stems are in some cases modified to perform as leaves. Butcher's Broom has very leaf-like branch stems and its leaves are tiny scales. The stems of cacti also act as leaves (and water stores too).





Fleshy plants contain a small amount of woody tissue inside their vascular bundles. The ring-like arrangement of the bundles gives strength as well as flexibility.



In the root, the woody tissues become concentrated in the centre. This gives roots a cable-like strength – ideal for anchorage.

Wood and how it is formed

Woody tissue, which is also called *xylem*, is built of millions of small cells. It is the toughness of the walls of these cells which gives wood its strength and hardness and which makes it so useful. The soft, elastic cellulose is reinforced by a hard substance called *lignin*. All mature woody cells are dead however. After the lignin has been deposited, the living contents of the cell disappear leaving only a tough, hollow structure behind.

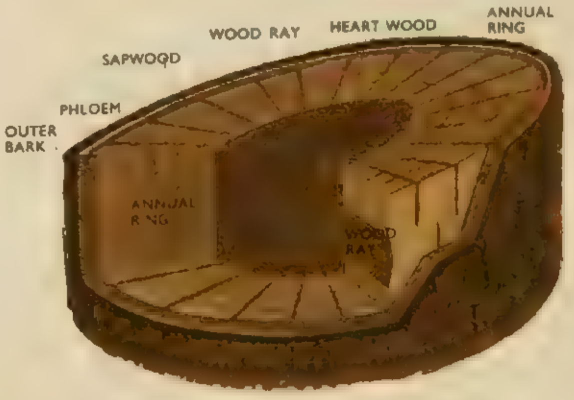
The water-conducting, woody tissues (xylem) are not just scattered about the plant. They are concentrated into small columns or *vascular bundles* along the length of the plant stem. At the bottom of the plant stem the bundles pass into the roots. Where leaves are produced, the bundles pass outwards into the midrib of each leaf.

Also in the vascular bundle, but on the outside of the xylem, is more conducting tissue called *phloem*. Phloem transports organic foods throughout the plant but the phloem cells are living and do not have lignin in their walls. Between the xylem and phloem of the vascular bundle is a narrow strip of simple, unspecialized cells. This is the *cambium*. Cambium is very important for the later growth of the plant.

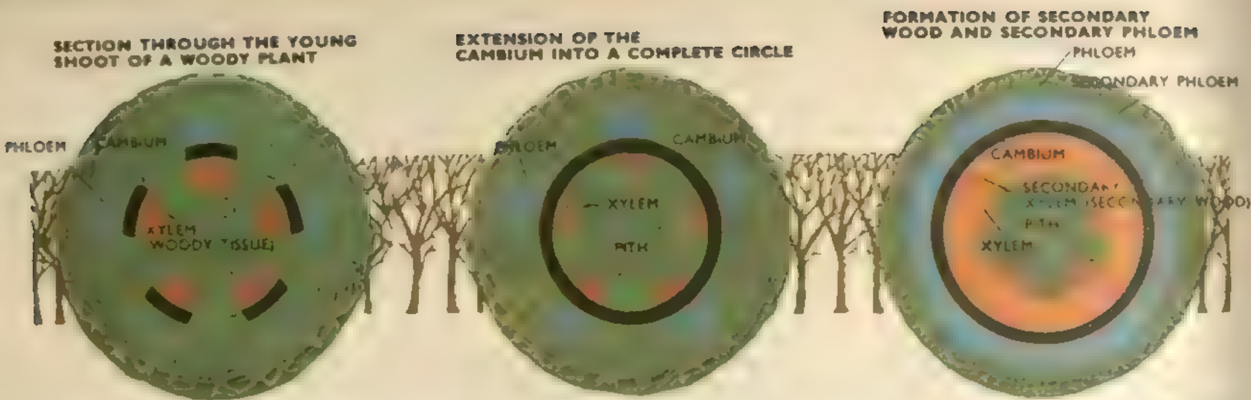
In 'fleshy' plants like the buttercup, which do not grow very high off the ground, the small amount of woody tissue in the stem is quite sufficient for transporting water and providing the extra support needed.

Larger plants such as trees grow year after year. As their size increases they need more and more wood for support. This wood is formed by a process called *secondary growth*. Secondary growth destroys the initial ring-like arrangements of the vascular bundles. Only in very young shoots, unthickened by

Cross-section through a tree trunk. The central heartwood, *coloured by gums and tannins, no longer conducts water. This function is carried out by the whiter* sapwood. *Phloem cells which conduct food are found on the inner layer of bark and consequently stripping it off may kill the tree. Simple woods have their* wood rays *a single cell thick. In more complicated wood such as oak, the rays are dozens of cells in width.*



SEGMENT OF
AN OAK-TREE TRUNK



Young shoots of trees have their vascular bundles arranged in a ring. Before secondary wood is formed the cambium (strip of dividing cells) spreads to form a circle. Secondary wood and phloem obscure the original position of the vascular bundles.

further wood formation, can the true position of the original bundles be observed.

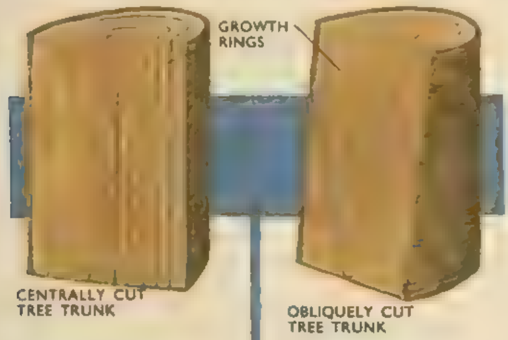
Secondary growth commences with division of the cambium cells in each vascular bundle. But soon the cambial activity spreads to cells lying between each vascular bundle. A complete ring of cambium is thus formed.

The cambium cells divide so that there is an inner and an outer daughter cell. The inner cell becomes lignified—that is, its cellulose cell walls become reinforced with lignin. The outer cell once more divides. In this fashion more and more wood is formed on the inside of the stem. And as the stem grows in diameter the cambium cells move further and further from the centre. Some secondary *phloem* is also produced by cambial cells. This time the outer daughter cell becomes specialized into conducting tissue while the inner daughter cell divides again. Secondary phloem is present in trees as the innermost layer of bark.

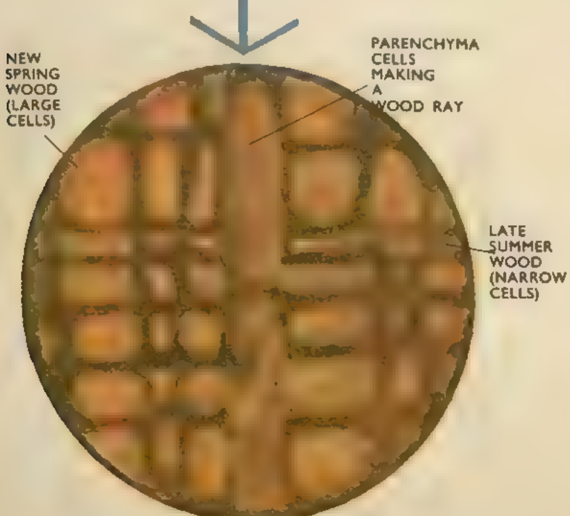
Not all the new cells produced by the cambium are in fact turned into conducting cells. A few remain small and simple and keep their living contents. These *wood parenchyma* cells are produced by certain sections of the cambial ring and form radial strips better known as *wood rays*.

At times of extreme cold, the division of the cambium cells slows down. In temperate climates this less favourable time for growth corresponds to the winter season. The interruption of the cambial activity is then preserved in a cross-section of the tree trunk as a dark circle—the so-called '*annual ring*'. The line is caused by the contact between two different-sized wood cells. At the end of summer, division is slowing down and the cells formed are very narrow; but the new growth in the following spring is very rapid and the cells are much wider.

A more accurate name for the 'annual ring' is a *growth ring*, for it is possible for more than one ring to form in a year. This may happen when a very cold spell occurs during the summer. In tropical countries where conditions are favourable for growth all the year round there are no growth rings at all.



If tree trunks are cut vertically downwards the growth rings will appear as straight lines. But usually the cuts are irregular. In this case the rings will appear as wavy lines—the familiar grain of the wood.



As tree stems become older and increase in size, the water-conducting activities may become taken over completely by younger wood nearer the outside of the trunk. The inner woody cells lose their conducting properties and may become filled with tannins and gums. Such substances may give this inner *heartwood* a distinctive colour which distinguishes it from the whiter, softer *sapwood* outside. The gums and tannins probably preserve the heartwood from fungal attack.

Year after year, secondary wood goes on forming. As the tree grows in height so does it increase in girth. In temperate regions, a growth ring indicates the passage of each year. When a tree has been cut down a close estimate of its age can usually be made by counting the rings.

Sometimes this is quite a task, for trees such as the oak and yew may live to great ages—600 years and more. In the forests of California the giant Redwoods and Wellingtonias are even older. Some are between 3000 and 4000 years old, without doubt the oldest living organisms known. Such trees were already of great age when the Romans invaded Britain in 55 B.C.

Wood is an important building material. It is used for making beams, poles and shingles as well as for constructing doors, furniture, window frames, barrels, musical instruments, boxes, tools and plywood veneers.

Wood is useful fuel for domestic heating. By distilling it, substances such as methyl alcohol, acetone, pitch, wood creosote, oil and gas are obtained. Resins, tannins and dye-stuffs are extracted from the heartwood. The ash left after burning wood is rich in potassium—a valuable fertilizer. Wood pulp is formed by mashing up wood so that the fibres separate and form a felt. Particularly valuable trees for manufacturing paper are spruce, firs and certain types of pine. The cellulose from wood pulp can be extracted, purified and turned into cellophane and rayon.

One of the reasons why they have survived so long is that their timber, rich in gums and tannins, is very resistant to decay. Another is that their fibrous bark is two feet thick and protects them against forest fires. Over such vast periods of time the trees have grown to colossal sizes. Some are 350 feet in height, 30 feet in diameter and have a root system which spreads over several acres.

Leaf Form and Function

WHILE sweeping up the autumn leaves one must wonder why the trees produce so many leaves only to drop them in autumn; why do plants have leaves at all; what is their purpose?

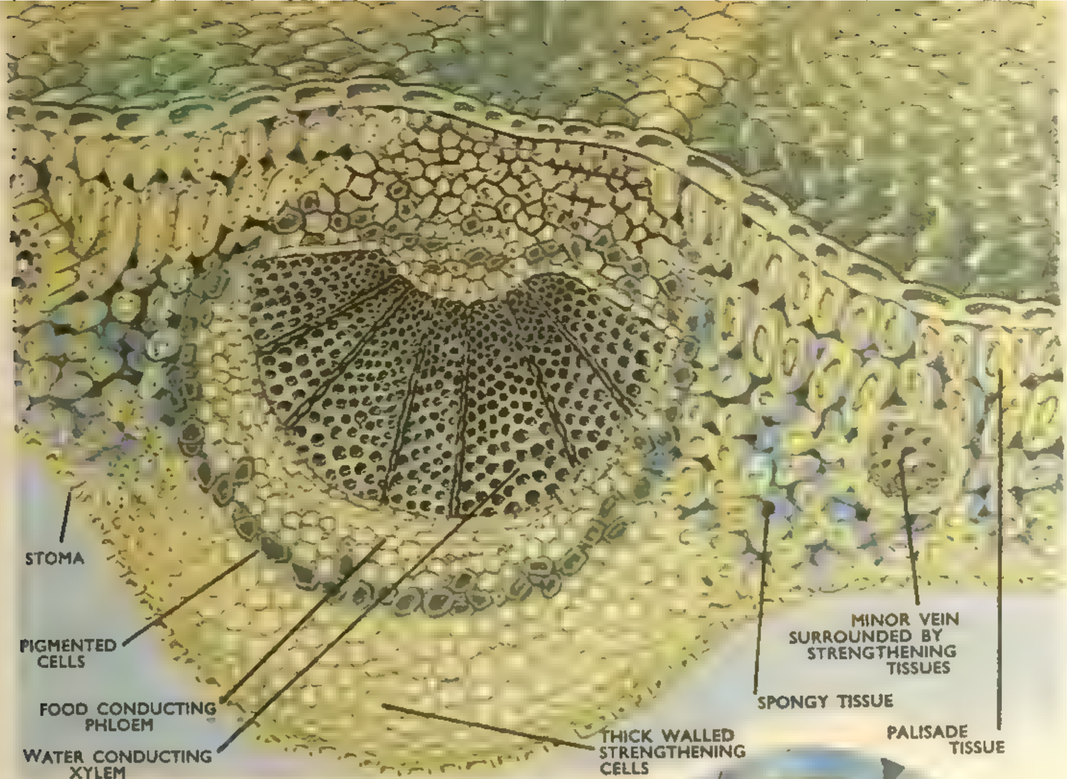
The leaves are actually the plant's *food factories*—delicate structures in which the vital process of *photosynthesis* occurs. This is the process of manufacturing sugars from carbon dioxide and water. A typical leaf (e.g. that of a beech tree) consists of a flat blade or *lamina*, and a stalk, known as the *petiole*, connecting it with the stem. Large-leaved plants such as rhubarb have large petioles—a stick of rhubarb is actually a leaf stalk. The slightly swollen part of the stem where the leaf arises is called the *node*. Each node may bear one or more leaves which are arranged in such a way that none is overshadowed completely by another. The angle between the leaf and stem is called the *axil* and normally contains a bud.

The first leaves of a plant are the *cotyledons* (cot-ill-eed-ons) or seed leaves. These are present in the seed. Flowering plants are divided into the *Monocotyledons* and *Dicotyledons* according to whether there are one or two seed leaves respectively. The cotyledons do not always come above ground when the seed sprouts and if they do they are usually unlike the later leaves.

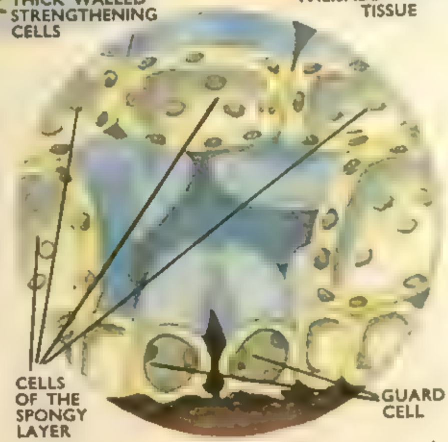
Running across a leaf are a number of ridges or *veins* which indicate the position of the conducting strands carrying water and food materials. In dicotyledons the veins form a network, but those of most monocotyledons run parallel to each other without forming a network: they show *parallel venation*. Monocotyledon leaves are usually long and fairly narrow, e.g. those of grasses, irises and daffodils. Leaf shapes of dicotyledons, however, vary enormously according to the arrangement of veins and the development of the lamina between them.

Detailed structure of a typical leaf

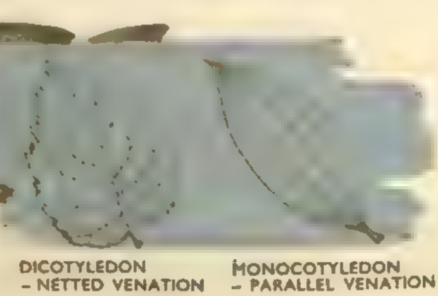
Internally the petiole is like a small stem. Vascular tissues convey water and food between leaf and stem. Strengthening tissue surrounds the conducting vessels. The lamina is covered with a waxy non-cellular film (the *cuticle*) which is normally thicker on the upper surface than the lower. The *epidermis* (one cell thick) may or may not carry hairs. Scattered all over the lower surface and appearing occasionally on the upper surface are tiny pores called *stomata* (singular: stoma), through which water, oxygen and carbon dioxide pass into and out of the leaf. The stomata are bounded by special cells (guard cells) which control the opening of the



A block diagram showing the structure of the main vein and the lamina of the leaf. (right) A close-up of a stoma (in section) and the surrounding cells of the leaf.



A twig of privet. Note the entire leaves with one major vein and the axillary buds at the base of each leaf. Insets: (left) the rose leaf (note the separate leaflets) has green stipules at the base, (below, left) netted venation of a dicotyledon, (right) the parallel veins of a monocotyledon such as lily of the valley.



pores. Beneath the upper epidermis is the *palisade layer* of rectangular cells which contain many *chloroplasts*. These are 'packets' of chlorophyll which give the plants their green colour, and in which the process of photosynthesis is carried out. The spongy layer contains irregularly-shaped cells and many air spaces which connect with the stomata. The veins stretch through the leaf tissues carrying water and food materials. The xylem is on top of the phloem and there is usually some strengthening tissue on each side of the vein. Leaves which stand erect (e.g. daffodil) usually have stomata distributed on both surfaces and palisade tissue on both sides.

Leaves that survive the winter (evergreens) and those of plants in desert regions have thicker cuticles and are modified to withstand drought; the stomata are protected by being sunk into pits or by the curling of the leaf. Evergreen leaves also have more strengthening tissue to withstand high winds.

Leaf fall

Leaves are periodically replaced in all plants—even in evergreens and tropical trees, but in these cases the leaves are not shed at once. Only the deciduous trees lose all their leaves at one time. When a leaf is to be replaced a corky substance forms between it and the stem. When this corky *absciss layer* is complete the leaf is connected to the stem only by the vascular (conducting) tissues. These snap in the wind or after frost and the leaf falls, leaving a scar on the stem. Leaf fall is thus a living process involving the formation of special tissues. Dead branches do not shed their leaves. Before leaf fall the leaf often assumes rich colours—the reds and golds of autumn. These are associated with chemical changes which accompany the breakdown of chlorophyll.

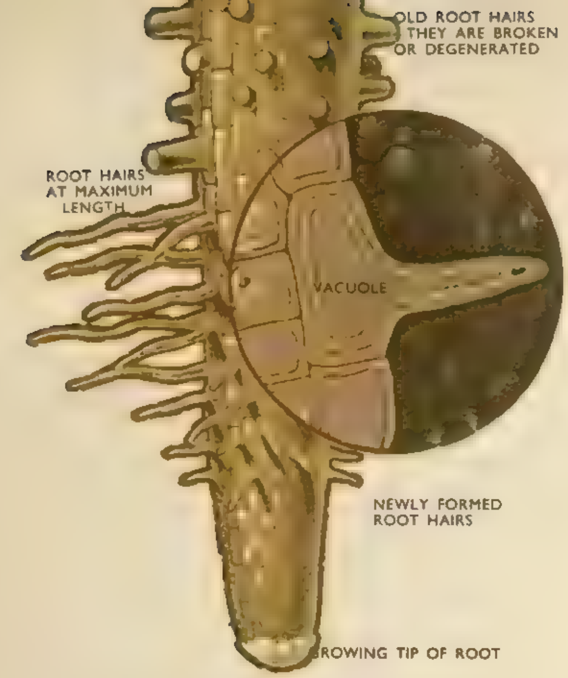
Variations in leaf form

The typical flat green leaf is often modified for other purposes. The plants known as *succulents* (e.g. stonecrops) have thick fleshy leaves which act as water stores for the plants, which usually live where there is irregular rainfall. Leaves for food storage are found in bulbs (e.g. the onion) whose fleshy leaves store food for the next season's growth.

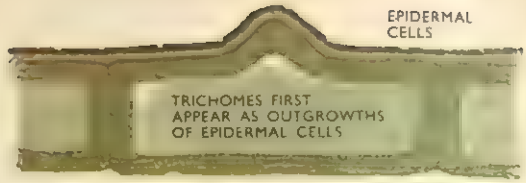
Tendrils are climbing organs which twine around supports. They may be modified stems, leaves or stipules. Those of a sweet-pea are modified leaflets of a compound leaf. Plants which trap insects to increase their food supplies have specially modified leaves which attract and trap the insects. Leaves may be reduced to spines (e.g. in the gorse) where the stem takes over the photosynthesis of food.

The simple leaf (5) has one major vein. The oak leaf (3) is toothed and intermediate between the entire and the compound pinnate leaf (1). The almost entire leaf (4) has several major veins (palmate condition). The compound palmate leaf of the horse-chestnut (2) is the final stage of development of this type of leaf.

Young gorse plants, however, have normal leaves. The small scales found on winter buds (e.g. the horse-chestnut) are also modified leaves and the petals and other parts of the flower are considered in the same way. Occasionally leaves are completely absent—the stem will then be photosynthetic. On the other hand, in the grass pea the petioles remain and look just like blades of grass.



Root hairs develop just behind the growing tip of the root. They increase the surface area through which water is absorbed.



Trichomes – plant hairs

The inside tissues of plants are protected by a tough outside layer called the epidermis. The cells which go to make the epidermis are usually short and squat. They have thick walls impregnated with fatty substances and so are impervious to water. In addition they are tightly packed together leaving no spaces between them for gases to penetrate.

Some epidermis cells also grow outwards. In this way they form appendages or trichomes. Trichome comes from a Greek word which means a growth of hairs. Some resemble the hairs of mammals, others are small and merely appear as numerous small 'bumps', while a few are modified into scales.

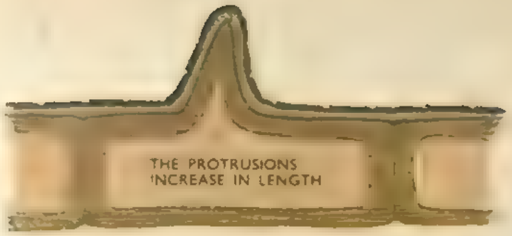
The shape, size and structure of the trichomes depend upon their functions – whether they are for absorption, protection, support, seed-dispersal or secretion.

Trichomes that cover the roots of plants are called root hairs. Their function is to increase the water-absorbing surface area of the root. The hairs are usually tubular in shape and grow directly outwards from the epidermal cells of the main root. Usually they are made of one cell only (unicellular) and are very small in size – between 5 and 20 microns in diameter and 80 and 1,500 microns in length (a micron is equivalent to one-thousandth of a millimetre). Their walls are thin and most of the inner cavity is occupied with a large vacuole or space. Living protoplasm is concentrated about the sides of the cell. The life of each hair is generally a short one. The cell collapses and the hair sloughs off. But as the root grows in length new hairs develop near the root tip. The old hairs are being replaced continually. A few hairs are known to live much longer but their walls become lignified (woody). They can no longer absorb water and mineral salts from the soil.

Numerous plant stems and leaves are covered with hairs. Thick coats of hair trap a layer of air against the plant surface. This layer, undisturbed by air currents, retains its moisture and also its temperature. Plants growing in cold climates or regions exposed to the drying conditions of strong sunlight or wind frequently have stems and leaves well covered in hair.

The hairs may consist, like root hairs, of only one cell (unicellular) or, by the formation of dividing walls, they may come to be many celled (multicellular). Unicellular and multicellular hairs may be branched or unbranched. The multicellular hairs may consist of one row of cells or many rows.

Sometimes the hairs are short-lived. They serve for protection only when the plant structures are in their early stages – then they are shed. Of the more persistent hairs, some retain their chlorophyll and keep their green appearance. Others lose their living contents, and the empty space inside them fills with air. Such hairs reflect a great deal



of the light that falls upon them and they give the plants a white or sheeny appearance.

Trichomes may also develop on the petals of flowers. They are so small that they cannot really be called hairs. Instead they are called papillae. They give the petals a soft, velvety appearance and prevent them from becoming wet.

Other trichomes develop as scales called peltate hairs. They are shield-shaped and are usually attached to the plant surface by a short stalk. They are most usually found on the underside of leaves protecting the 'breathing' pores of the plant (stomata). They also develop on some young buds and give protection against drying up.

The cell walls of trichomes are commonly made of cellulose. They may however become lignified (woody) or even stiffened by deposits of either silica (SiO_2) or calcium carbonate ($CaCO_3$). The sharp rigid hairs give the plant protection against small crawling animals, such as slugs and snails.

Stiff hairs may also assist plants in climbing and adhering to surrounding surfaces. On some climbing plants the hairs may even be hooked, e.g. goose-grass. Many plant hairs produce secretions – most glandular hairs are multicellular – a number of cells forming a stalk and head. The actual secretory cells of the structure have large nuclei and dense protoplasm. Droplets of secretion can be seen inside the living tissues of the young cells. By the time the cell is mature the fluid has usually come to lie between the cellulose wall and the cuticle. When the cuticle breaks down the fluid is released.

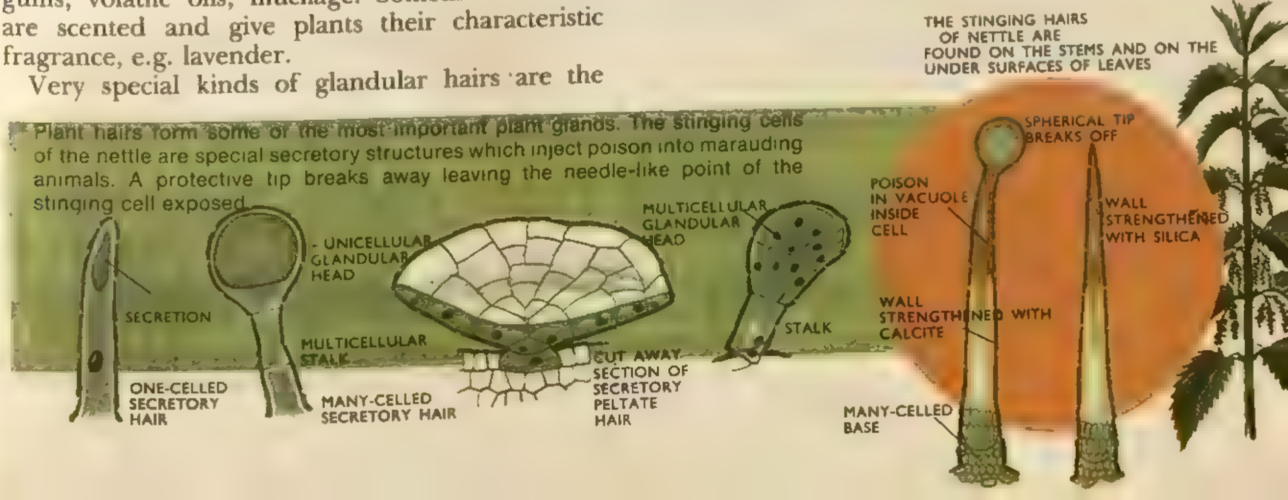
The substances secreted vary with plants – resins, gums, volatile oils, mucilage. Sometimes the oils are scented and give plants their characteristic fragrance, e.g. lavender.

Very special kinds of glandular hairs are the stinging hairs. They are perhaps best known on the common nettle. The hair is made of a single secretory cell embedded in a multicellular epidermal stalk. The cell walls of the secretory cells are reinforced with calcite in the lower half and silica in the upper regions. Within the living protoplasm is a large vacuole filled with a complex chemical poison.

Quite broad at its base, the hair tapers to a point near its apex, and then expands into a small spherical tip. If the hair is disturbed by an animal the tip breaks off along a predetermined line of weakness; the sharp tip of the stinging hair is left exposed. It penetrates a skin surface easily. The compression of the bladder-like stalk drives the poison material contained in the main part of the secretory cell into the wound. The poison is a complex substance known to contain histamine and acetylcholine. Inside the skin, it sets up an irritation and causes swelling and flushing of the skin surface.

Stinging is not confined to the nettle. A few plants belonging to three other families are known to have stinging hairs. One Indian stinging plant *Tragia cannabina* has, as a needle, a crystal of calcium oxalate. If the stinging cell is depressed by contact with a passing animal, the crystal is forced forward, penetrates the skin, and breaks off. Poison enters the body of the animal through the puncture.

Though the hairs differ in detail, their manner of operation is very much the same. But the severity of the poison, however, varies. In the case of the Devil or Fever Nettle of West Africa it can cause fever and sometimes death. So powerful is the poison that even wild elephants are said to avoid coming in contact with the plant.



Plant hairs form some of the most important plant glands. The stinging cells of the nettle are special secretory structures which inject poison into marauding animals. A protective tip breaks away leaving the needle-like point of the stinging cell exposed.

Water and plants

When a plant is cut and the cut shoot is left without water it quickly wilts. Water is lost by evaporation; the cells lose their shape and turgidity and the whole plant becomes limp and floppy. Water is therefore of prime importance to the structure of a plant. Water plants may contain up to 95% of water, and even a sturdy tree is half water in terms of weight.

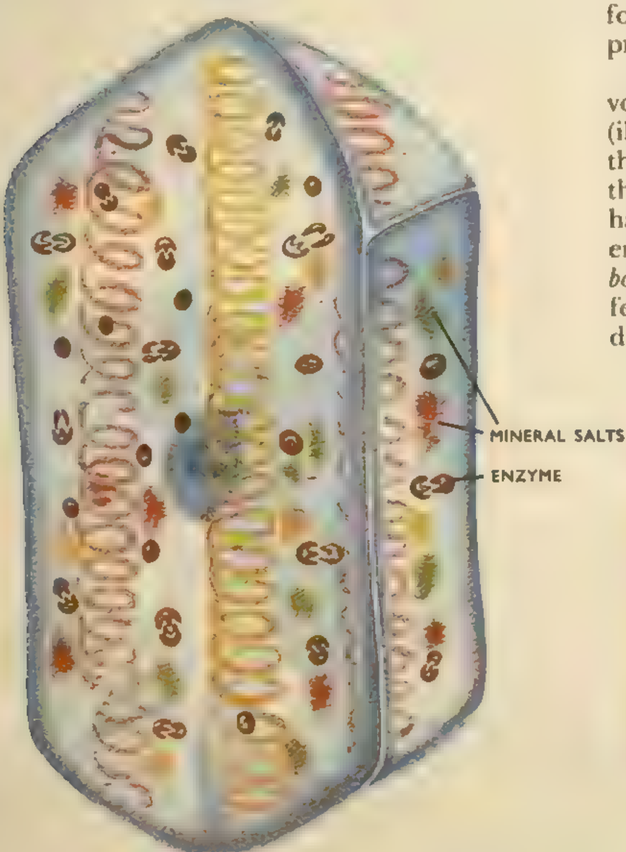
Not only does water control the shape of plants—it is the basis of living protoplasm. It is the medium in which all the processes of life go on. Water is the solvent for the mineral salts used in nutrition and for the sugars produced by photosynthesis.

An experimental inquiry into water and plants

Plants contain water: they cannot survive without it. But how do they obtain water? How much do they absorb? Which parts absorb it? How is the intake of water affected by outside factors such as soil and climate?

Some of these questions can be answered by means of simple experiments. The problems to be overcome in performing these give some idea of how a scientist who makes a discovery actually works.

A young plant cell cut away showing schematically the movement of food materials (spirals).



Do plants absorb water through their roots and how much do they absorb? The roots of a plant are placed in a measured volume of water. If the plant takes in some of the water, then the volume will get less.

What sort of plant and container will it be most convenient to use, and how can losses of water other than into the plant be prevented?

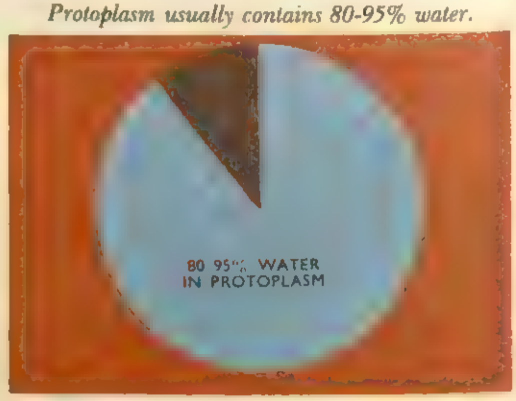
A plant with a small root system is easy to handle, in which case a boiling tube or similar size container will suffice. Groundsel *(Senecio vulgaris)* is a small, common weed supplies of which are plentiful. When lifting the plant from the soil the roots must have a good covering of soil to avoid damage and this must be removed by careful washing in a gentle stream of water.

As the apparatus is shown set up in the illustration A (top right) an important factor has not been allowed for. No account has been taken of water lost to the air by evaporation.

This problem *may* be solved by putting a layer of oil on the water surface to prevent evaporation. However, this prevents water vapour escaping and the exchange of other gases—oxygen and carbon dioxide, for example—which may affect the result, for roots, like all living tissues, consume oxygen and produce carbon dioxide. Is there an alternative?

One is to set up a second tube with the same volume of water as the first but without a plant (illustration B). The two tubes are kept together for the duration of the experiment. This ensures that the only difference between the two tubes is that one has a plant in whilst the other does not. When, at the end of the period decided on for the experiment, *both* final volumes of water are measured, any difference in the volume of water absorbed must be due to the presence of the plant.

Protoplasm usually contains 80-95% water.



For measuring the volume of water measuring cylinders may be used but these are accurate only to the nearest cubic centimetre, not less. Moreover, when the plant is taken out of the water at the end of the experiment water clinging to the roots is lost and so will give the plant credit for absorbing more water than it actually did absorb. Illustration C shows how this can be overcome.

Deductions from results

From the usual result in this experiment it is obvious that a plant does absorb water through its roots and a measured volume of water is absorbed in a given time by each plant. Taking the results of a class, data should be available for a number of plants. Does size determine the rate of uptake of water? How would you measure the plants and could you plot a graph showing the size of plants as one axis and the volume of water absorbed in a given time as the other?

The problem of absorption

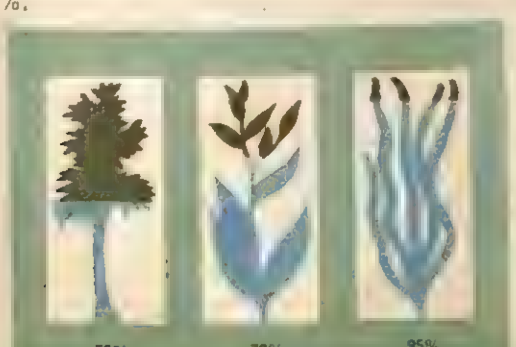
Having been able to show in the last experiment that roots absorb water (only the roots were in water), the problem now facing us is how does water pass from outside the root to inside, that is, how is water *absorbed*.

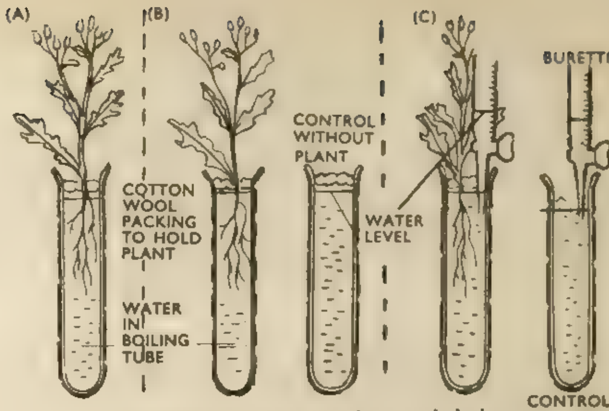
Water can be moved from one place to another in several ways—pumped through pipes, evaporated and moved as a gas, taken up by capillary action as when blotting-paper absorbs water and so on. The structure of the root should help us decide which method operates in the plant.

The structure of a root

a. Place the end two cms. of a groundsel root in water on a glass slide and examine under the low power of a microscope.
b. Look at the drawing on page 135 of part of a section through a root. What do you see, at the outside of the section—the part which will have contact with the soil? What do you see at the centre of the root and between the centre and the outside? Do any of these observations help you to explain how water is taken into a root? Do you think plants could absorb water in the same way that blotting-paper absorbs water? What pathway would the water take if this were true?
c. Soil 'solution' and the blotting-paper theory.
Plants do not grow normally with their roots surrounded

A tree (left) contains about 50% of water by weight, (centre) a herb about 70%, and (right) a water-dwelling plant as much as 95%.





Absorption experiment with groundsel plant.

by distilled water. Soil water always contains substances in solution. Does the solution outside the roots affect the rate of water uptake? If the 'blotting-paper theory' is correct, it should have little effect. This can be tested by experiment. If we take two similar sized plants, which would absorb similar volumes of water under the same conditions in the same time, and place one in water and the other in a solution, then if the blotting-paper theory is correct equal volumes of water and solution (water plus dissolved substances) should be taken up in the same time.

Absorption experiment

Set up two similar groundsel plants at the same time, one in water (40 mls.), one in 9% glucose solution (40 mls.).

Measure the volume absorbed over a period of about 60 hours. (A class which set up 15 such experiments found that in 11 cases the plants in water had absorbed twice as much as the plants in 9% glucose solution—but in both cases absorption had occurred.)

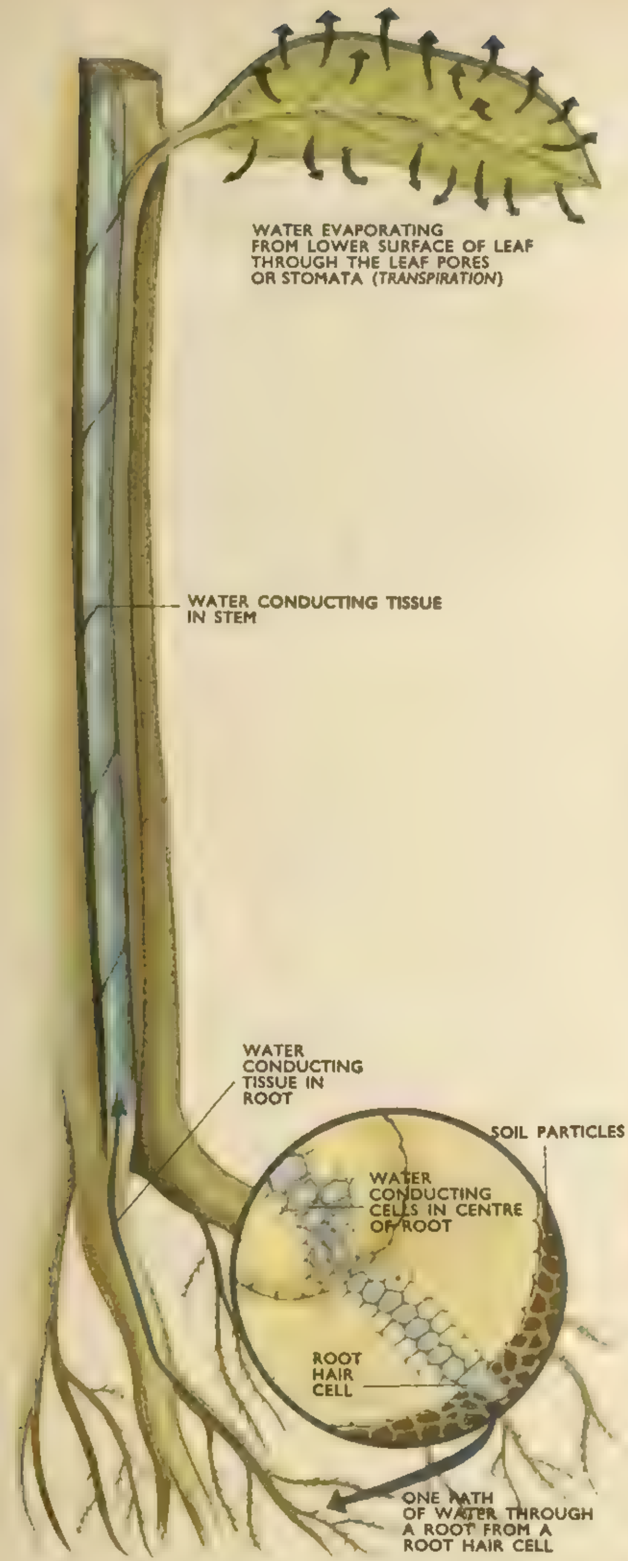
Can the blotting-paper theory account for all or part of the absorption?

The effect on absorption of dissolved substances in the water bathing the roots.

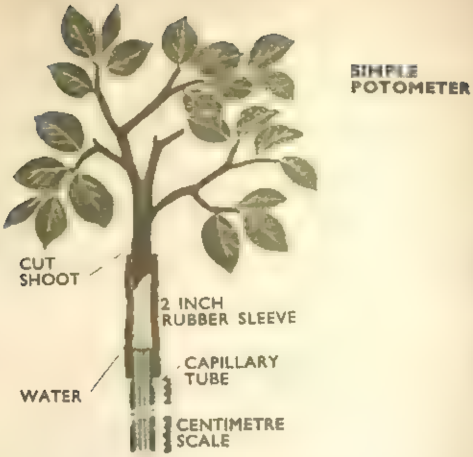
The result of the previous experiment clearly indicated that the presence of a dissolved substance in the water surrounding the roots affected the rate of absorption. The root is made up of cells with spaces between cells. Water could enter between cells, by the blotting-paper method, but is water actually entering cells?

Detailed examination shows that a root cell has the following structure (taken from the middle cylinder—cortex—seen in section).

Water helps to give the parts of a plant shape just as the air does in a cycle inner-tube.



The transpiration stream



To set up the apparatus the capillary tube and rubber connecting tube are filled with water and the base of a cut shoot is placed immediately after cutting into the rubber tube so that air bubbles are not drawn up into the water vessels of the stem. A scale 10 cms long marked off in cms can be stuck to the tube, and by timing the rate of passage of the end of the water column the relative rate of absorption can be measured under different conditions. If rate of absorption equals rate of loss we may measure variations of transpiration rate in this way.

The vacuole contains water. Water must have been able to get into the cell.

It would be interesting to find out if the presence of a solution outside a cell affected its water content.

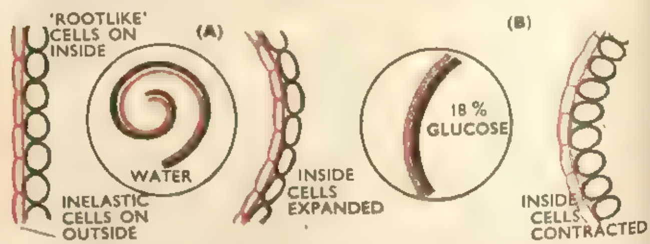
An indirect but simple way of finding out if water is entering or leaving cells.

Cut 1 inch of dandelion stem into quarters, place one ¼ in water, a second in 9 to 18% glucose. Observe for ten minutes. Now reverse the solution and again observe.

The outside of the stem is made of cells which will not stretch very much. The inside of the stem is made of cells very similar to those of the root which we are considering. (Compare the behaviour of the stem with the action of a bi-metal strip on heating.)

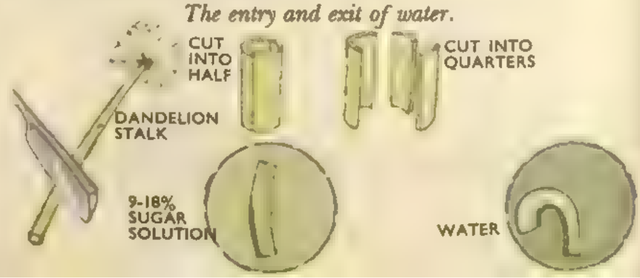
A little theorising.

Consider what it means when the ¼ stem bends.



The diagrammatic results illustrate the next problem very clearly. The inside cells have expanded in water, but contracted in solution. Something has gone in in (A)—this could only have been water. Something has come out in (B)—this could have been either water or solution.

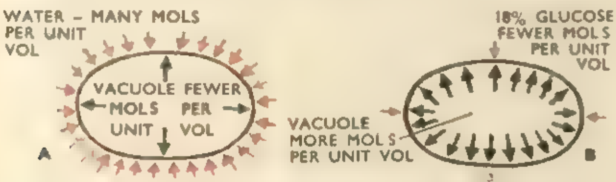
The entry and exit of water.



Taking the first case first, we have a further problem—what caused water to go into the cell? Perhaps water also came out but at a slower rate. But what caused the water to move at all?

Water molecules (like all molecules of any gas or liquid) are in a state of random movement, colliding with each other and with any surface with which they come into contact. Now imagine what would happen if water was in contact with a skin which had holes in it, large enough to let water molecules through. Occasionally, a molecule would 'hit' a hole and go through. If water were on both sides of the skin, it would pass equally in either direction *if*, and only if, there were equal numbers of water molecules on both sides of the skin. If there were more water molecules on one side, there would be more 'collisions' with holes and more water molecules would pass one way than the other

We can apply this theory to the dandelion cells: more molecules will pass in than out (A)



Now take the second case. A cell in an 18% glucose solution shrank, presumably because more water molecules passed out than in. If 18% glucose contains less molecules of water per unit volume than the vacuole solution the following may happen (see B): more water would pass out than in.

But what about the other substances, sugar molecules and dissolved vacuole substances, why don't they pass in and out? For this theory to work we must assume either that the skin will not allow them through at all or it allows only a few in compared with the number of water molecules.

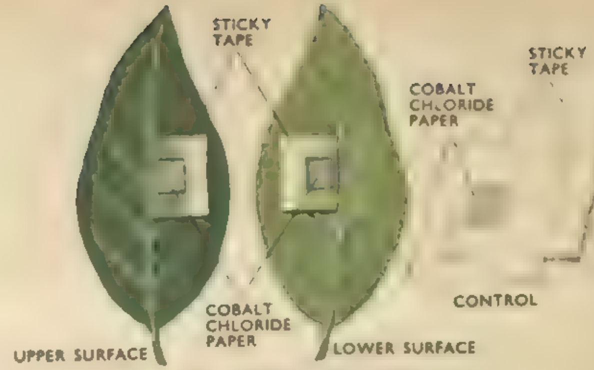
A plant cannot move about from place to place in order to obtain water as a land animal can. It obtains a supply of water through its roots. These often spread through a large volume of soil in their search for water. Water actually enters the plant through the root hairs. These contain more dissolved substances (e.g. sugar and salts) than there are in the soil. Because of this difference in concentration between the inside and outside of the plant, water will pass into the root hairs through the root hair cell walls by a process called *osmosis*.

The water which enters the root hairs dilutes the sap within them so that the concentration of dissolved substances is less than that of inner neighbouring cells and eventually reaches the centre of the roots. This is the most favoured explanation of how water enters a plant.

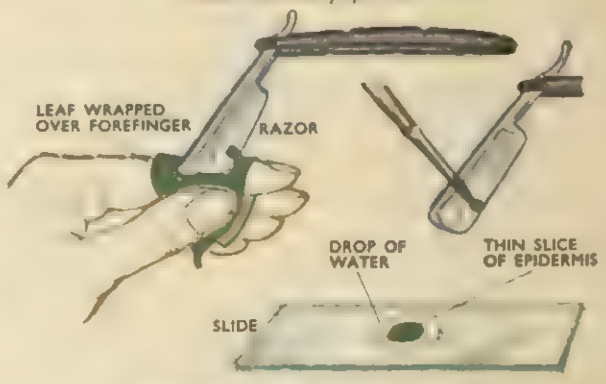
Water loss—transpiration

The loss of water from plants by evaporation is called *transpiration*. This can be demonstrated experimentally and the rate of transpiration can be measured.

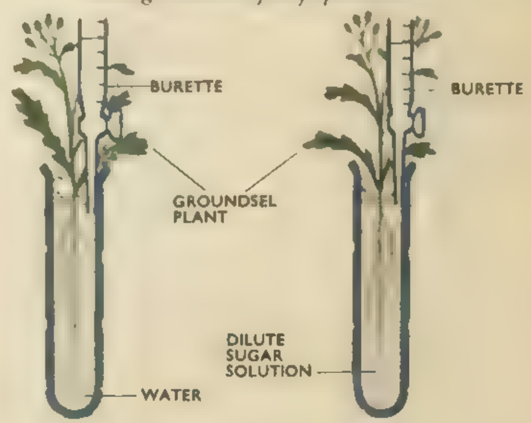
The illustration shows a simple sensitive potometer apparatus for measuring the rate at which a leafy



Cobalt chloride paper test

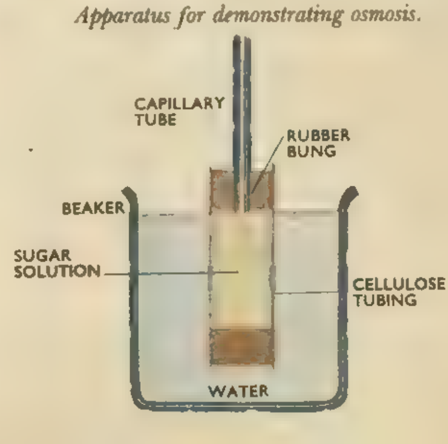


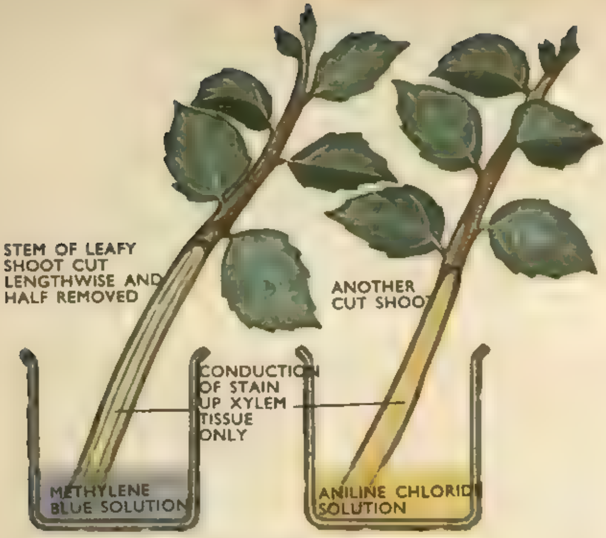
Cutting a section of leaf epidermis



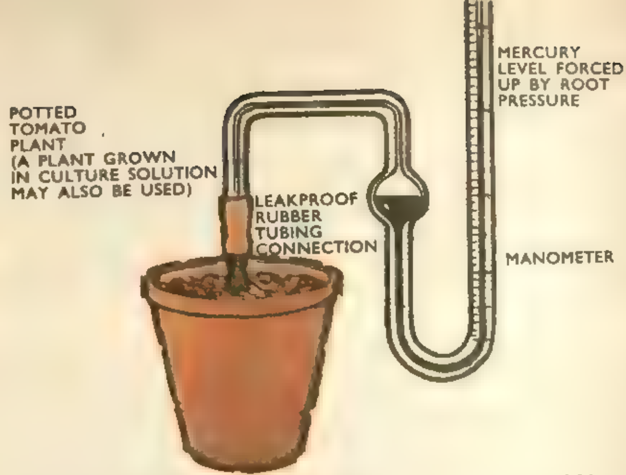
The effect of dissolved substances on rate of uptake of water.

Apparatus for demonstrating osmosis.





The paths of water conduction.



A vigorous plant such as a tomato plant is cut to within a couple of inches of the stem base. If it is well watered, liquid will exude from the cut surface, forced out by root pressure. This pressure can be measured by connecting the cut stem to a manometer. The change in the levels of mercury indicates the size of the root pressure, which may be up to one atmosphere. This is not large enough to send water up to the top of a large tree although it could be sufficient to supply smaller plants. Root pressure is greatest during spring.

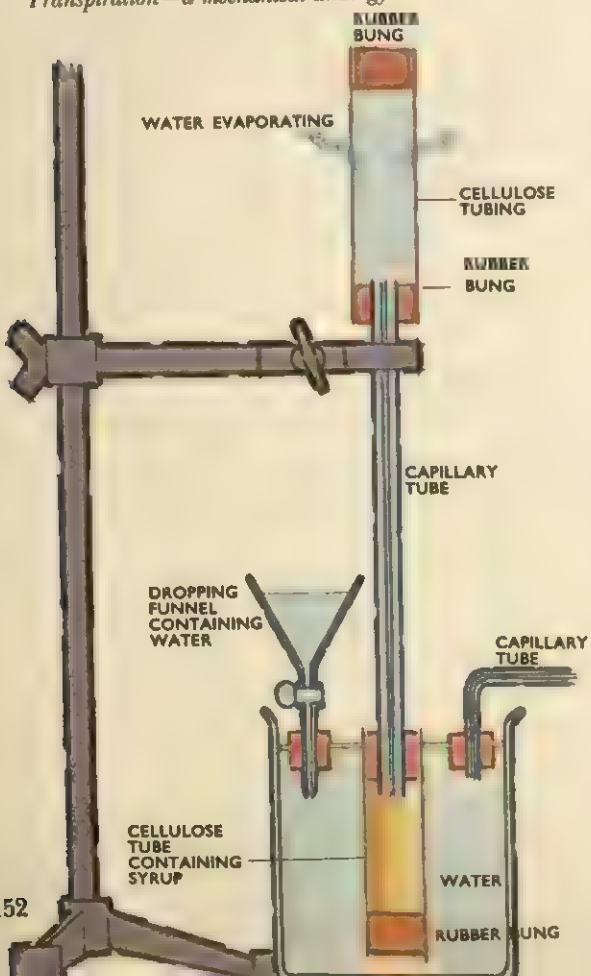
shoot takes in water. This is not quite the same thing as measuring the water loss, for green plants use some water for photosynthesis – their food-making process – and may retain water for other purposes. However it has been shown that usually rate of uptake equals rate of loss.

The effect of various climatic factors – wind, humidity, temperature, etc. – on transpiration can be studied by using a potometer in a hot, dry atmosphere, in a hot, damp atmosphere, a cold, damp atmosphere, and in moving air by using a fan. By removing a leaf at a time it is also possible to study the relationship between the number of leaves and the rate of transpiration.

Is water lost through both upper and lower leaf surfaces equally? This can be determined by first measuring transpiration rate, then Vaselining the upper surfaces of the leaves of one shoot, measuring transpiration rate, and Vaselining the lower surfaces of the same shoot and remeasuring transpiration rate, having cleaned the upper surface of Vaseline. The rate of water uptake can be measured in both instances if the shoots are placed in the potometer. The experiment with cobalt chloride paper which is sensitive to water also demonstrates this. By slicing thin strips of epidermis off both surfaces of a leaf (see illustration – laurel is very suitable for this purpose as for all transpiration rate experiments) the number of pores (stomata) on each leaf surface can be counted for a given area. The results of this can be correlated with those of previous experiments.

From all the experiments we know that water is lost from the leaves. But where does the water come from? The first experiments show that a plant's roots absorb water. Is the water lost in transpiration the same as that taken in primarily through the roots? The potometer experiment shows that a cut leafy shoot 'sucks' up water through its stem

Transpiration – a mechanical analogy.



and loses water through its leaves. The actual passage of water up a shoot can be seen if it is cut lengthwise and placed in a beaker containing methylene blue. The stain colours only the water-conducting tubes (xylem) of the stem which appear as a blue line. A shoot placed in aniline chloride shows a similar result. The woody walls of the xylem vessels contain lignin which is stained yellow by aniline chloride. Only the xylem vessels are stained. Therefore water is conducted only through the xylem vessels.

How does water move up the stem?

One of the most puzzling problems in plant physiology is that of the vertical movement of water through the plant. Its point of entry through the root hairs may be 340 ft. below the leaves. To lift water this height requires a force of 10 atmospheres. How and where can a plant develop such forces?

The water in the xylem tubes must be pulled from above, pushed from below or squeezed from the sides.

Look at the diagrams of apparatus on pages 150-2 and decide which is being used to demonstrate and measure (a) a push from below, (b) a pull from above. How could you demonstrate a squeezing force?

The actual 'pull' due to transpiration is enough to raise water up a small shoot and may suffice in a small herb, but how is water pulled up to the top of a tree three hundred feet high? The following theory is most widely held. The leaves are rich in sugar and other substances built up in photosynthesis. As water is evaporated from the outer parts of a leaf by the heat of the sun the sap of the cells there becomes much more concentrated. So they draw water from neighbouring cells to replace the water which has evaporated. This process spreads from cell to cell and back to the stem itself. This reduces the pressure in the water-conducting vessels of the stem and so creates a pulling force many times that of atmospheric pressure. The result is that water is drawn from the stem into the leaf. There are many thousands of leaves on a large tree. Since water tends to stick together in a narrow tube and a huge pulling force is needed to break such a column of water, the whole column of water from the top of the stem down to the roots is pulled upwards (see cellulose tubing experiment opposite). The stream of water between soil and leaves is known as the *transpiration stream*.

Besides the capillary force pulling water up from the leaves, other forces may help, though only to a small extent in a tree. The tissues of the root exert a small pressure known as *root pressure*. Just what causes this is not known but it can be measured (see experiment opposite). If one end of a narrow tube (capillary tube), which is open at both ends, is placed in a beaker of water the water will rise above the level of water in the beaker. This *capillary rise* (capillarity) in a typical experiment would be around six centimetres. Obviously root pressure and capillarity are not sufficient on their own to account for the rise of water up the trunk of a tree over three hundred feet high.

Nutrition

Food storage in plants

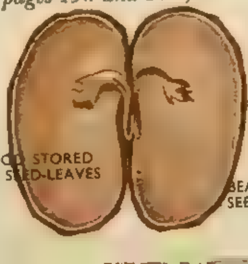
Some plants grow from seed, flower and produce more seed all in one season. These are *annuals* and they store relatively little food, for it is used up straight away in forming new tissues. Other plants, however, live for two or more years. Except in tropical regions, there is a definite growing season. In winter, deciduous trees drop their leaves and the above-ground parts of many herbaceous plants die. They must, however, have stored sufficient food to enable them to start growth in spring. Trees store food in the tissues of the trunk and branches but many herbaceous plants have special underground storage organs. These may be modified roots or stems.

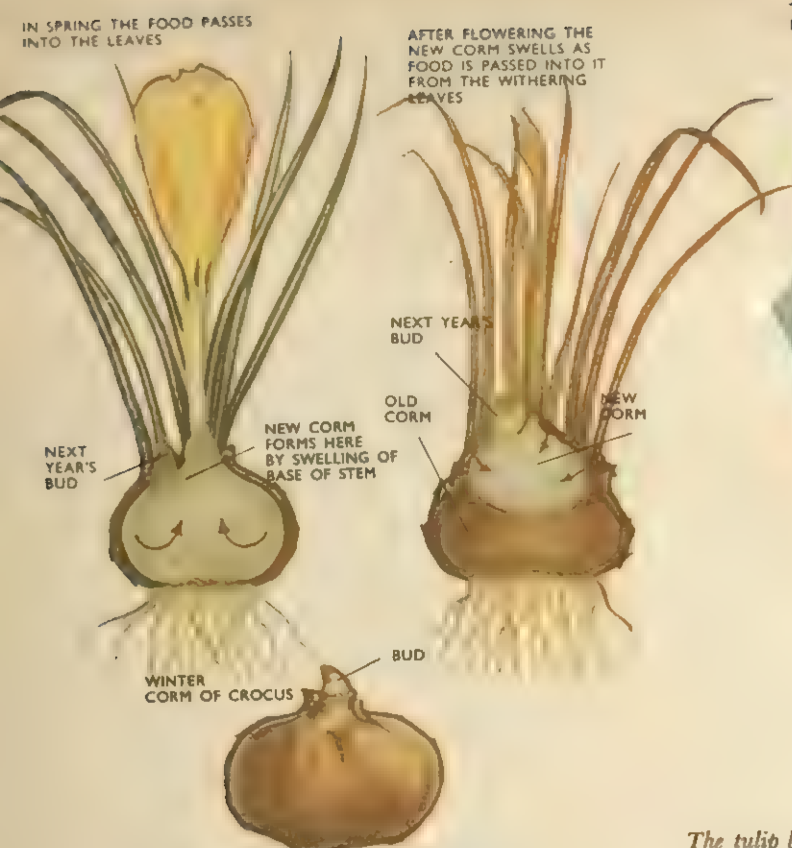
Storage in swollen tap roots is common in *biennials* (plants that grow and store food one year and flower and die the next). The carrot is an excellent example. By digging up carrots at the end of the growing season, Man makes use of the food that would have gone to make the next year's growth. Root tubers are found in dahlias and the lesser celandine for example. They develop from tiny buds at the base of the plant. They swell as food is passed into them and remain in the ground after the aerial parts have died down. Each tuber and its bud can give rise to a new plant.

Underground stems are the most common storage organs. They vary in structure but differ from roots in the possession of scale leaves and buds. Rhizomes are horizontal underground stems and are found in irises and many grasses. They do not always store food but when they do they are quite thick. The potato tuber acts as a reproductive body.

Corms and bulbs are both underground storage structures and are often confused. In corms, the

Food storage in bean seed. (For Solomon's Seal rhizome and dahlia tuber see pages 136 and 140.)





A corm stores food in the swollen stem. Buds develop on the corm which develops each year from the base of the flower shoot.

The tulip bulb stores food in fleshy scale leaves. Food from the green leaves passes to the scale leaves of the new bud which makes the next year's bulb.

food reserve is stored in the swollen stem, while in bulbs, swollen scale leaves or the swollen bases of the previous year's green leaves contain the food.

Seeds are, of course, supplied with food reserves that enable the young plant to establish itself until it can begin to manufacture its own food.

The most commonly stored food material is starch, but sugars and proteins are also stored. Fats are frequently important reserves in seeds while the reserve of the date seed is mainly cellulose.

Testing plant food reserves

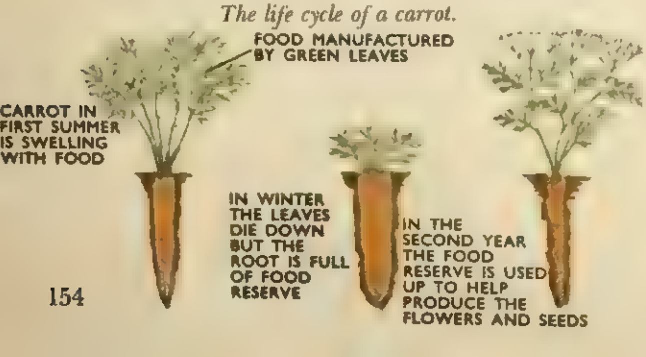
Plants store food so that they can survive harsh wintry conditions and begin to grow again when the weather gets warmer. Roots and swollen underground stems are the main storage organs in plants that die down for the winter. Seeds, too, contain food reserves that supply the young plant until it can manufacture its own food (i.e. until it opens its leaves and begins photosynthesis).

All three main classes of food material (carbohydrates, fats and proteins) are found in plants. Carbohydrates—compounds containing carbon, hydrogen and oxygen—are the most frequent reserve materials, the commonest of them being *starch*. This material is insoluble and occurs in the cells as tiny grains. Each grain is made up of many layers. The potato and the seeds of cereals are among the many starch-storing bodies. When iodine is added to starch, a deep blue colour appears and this is a simple test for the presence of starch. A drop of iodine solution in potassium iodide, put on a slice of potato, stains the starch grains blue.

Inulin is another common reserve and is closely related to starch. It is, however, soluble in the cell sap and does not react with iodine. Addition of alcohol to a thin section of a dandelion root or a dahlia tuber will deposit inulin crystals which can be seen under the microscope.

Sugars are found as reserve materials in some

The life cycle of a carrot.



plants. *Glucose* ($C_6H_{12}O_6$) is dissolved in the cell sap of onion bulb scales and is therefore invisible. It can, however, be detected with *Fehling's solution* containing cupric oxide in alkaline solution. Glucose reduces the cupric oxide to give a reddish-brown deposit of cuprous oxide. This indicates the presence of glucose or one of the closely related reducing sugars.

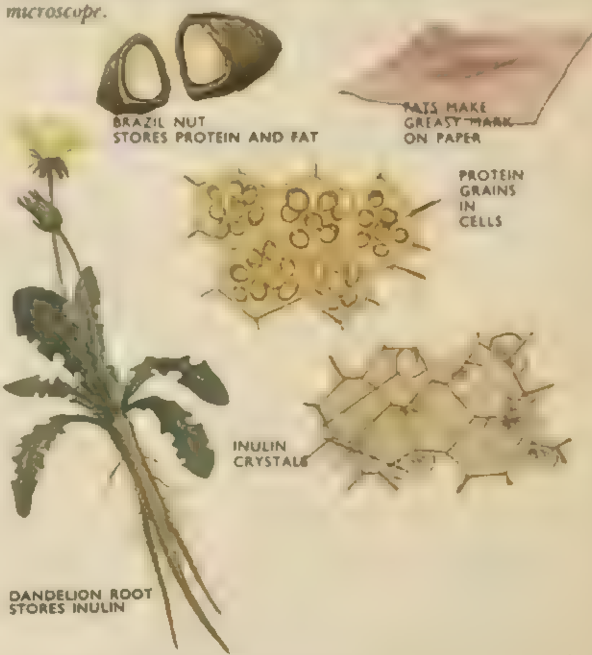
The reserve of the beetroot is *sucrose* ($C_{12}H_{22}O_{11}$), also known as cane sugar, because it occurs in the stem of sugar cane. The sugar beet is a variety of beet especially rich in this sugar. Sucrose will not, however, reduce Fehling's solution for it has no affinity for oxygen. Sucrose can be split into glucose and fructose molecules by heating with dilute hydrochloric acid. Glucose and fructose can be detected with Fehling's test.

Cellulose is the major constituent of plant tissues but may form a food reserve. The cell walls of the date seed are thickened with cellulose which acts as a reserve. Cellulose is stained violet with *Schultze's solution* which contains iodine and zinc chloride.

Carbohydrates are the main food reserves of plants but *fats* and *proteins* also occur—especially in seeds. Castor-oil beans and ground-nuts are good examples of fat-storing seeds. A simple test for fats is to rub the material on a piece of paper. A greasy mark is produced that lets light through. The oil globules also stain red with a dye called *Sudan III*. Proteins appear as grains in numerous seeds and are stained brown by iodine. *Millon's reagent* stains proteins a brick-red colour.

Many of the food reserves are in a solid and unusable form. When they are required, enzyme action converts them into usable compounds. They are then carried around in the plant to where they are needed.

Addition of iodine to starch produces a blue colour. The starch grains are made up of concentric layers as shown (inset) by the microscope.



Crystals of inulin appear when cells are washed in alcohol.

Enzymes, the organic catalysts

A practical problem

Read the account of the experiment on saliva on page 56 and your own records of that practical work before you tackle this.

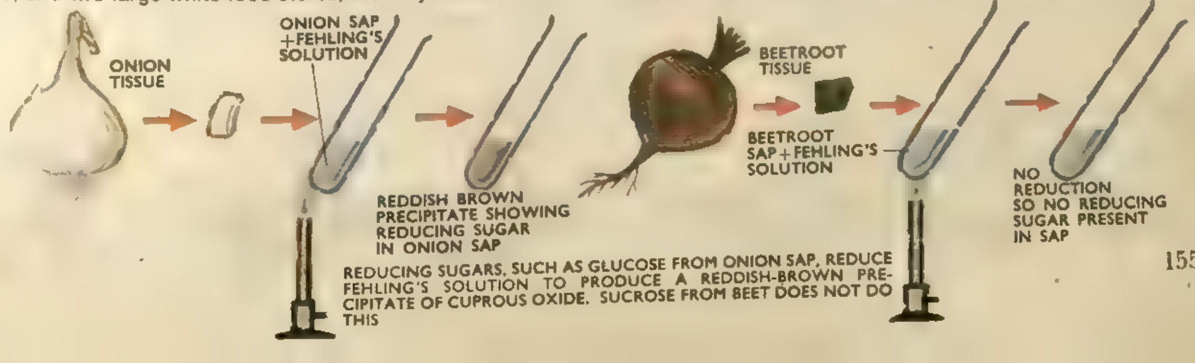
(a) Open a broad bean seed which has been soaked in water at room temperature for 60 hours in a shallow dish of water so that it has access to air and a lot of water. Remove the outer coat of the seed. Open the seed like a book with the long side of the D towards you. You will now see the embryo, and two large white food stores, the cotyledons.

(b) Remove a little cotyledon and test for starch. Also test cotyledon for reducing sugars.

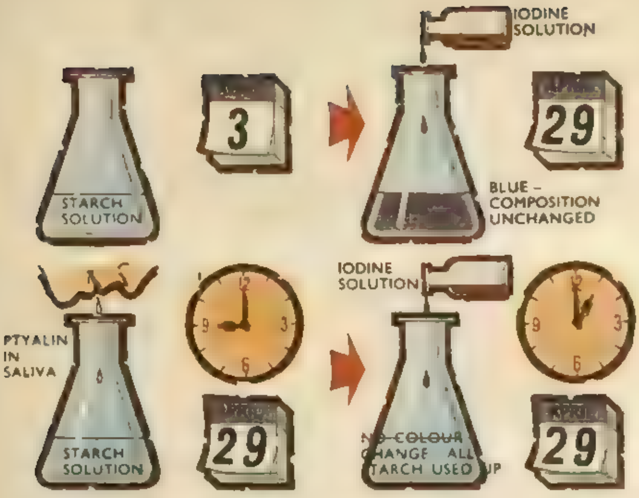
(c) Repeat the tests on the embryo.

What differences do you find?

When the embryo grows the dry weight of the embryo (total weight minus weight of water) increases and the dry weight



REDUCING SUGARS, SUCH AS GLUCOSE FROM ONION SAP, REDUCE FEHLING'S SOLUTION TO PRODUCE A REDDISH-BROWN PRECIPITATE OF CUPROUS OXIDE. SUCROSE FROM BEET DOES NOT DO THIS



The composition of starch solution will remain unchanged if left to stand for weeks on end. The continuing presence of starch can easily be confirmed, for by adding a drop of iodine solution to starch a dark blue compound is formed.

Some saliva is transferred from the mouth to another portion of starch solution, which is kept at body temperature. After a few hours the solution is tested with iodine. It does not turn blue, so the starch must have decomposed. Further tests show that sugar is now present in the solution. This reaction has been helped by ptyalin, *a substance present in the saliva. However, ptyalin has not been used up in the reaction—ptyalin acts as a catalyst. Catalysts produced by living organisms are called* enzymes.

of the cotyledon decreases. It seems that starch must be transported to the growing embryo. But how? It is not soluble in water, it is not found in the embryo. Does the embryo produce any enzymes able to digest starch?

(a) Take 20 to 30 bean embryos from seed prepared as described and grind them up in a mortar containing a *little* distilled water and thus obtain an extract from the broken-up cells of the embryo (adding a little well-boiled, but cool, sand helps the extraction).

(b) Make up a very dilute starch solution by adding starch paste to boiling water. Now add water to starch solution until the solution just fails to give a blue colour with iodine solution. Add a little starch solution at the original strength to the mixture, thus obtaining a dilute starch solution which just gives a blue colour with iodine solution.

Use this extract and starch solution to find out:

a. If extract contains starch.
b. If extract contains reducing sugar.
c. If extract contains a substance able to change starch to another substance.
d. If extract contains a starch-splitting enzyme.

N.B. To give any chemical change under these conditions it will be necessary to mix extract and starch thoroughly in proportions of about 1 to 9 and at about 30°C for 30 minutes. Make sure the 1 to 9 mixture gives a positive iodine test at the start by testing a sample.

Many chemical reactions, in particular a large number which occur within all living organisms, would be very slow if it were not for the action of catalysts. Although the catalysts do not themselves undergo any permanent chemical change, their presence, even in very small quantities, can change the rate of a chemical reaction to a remarkable extent.

Catalysts are very important in the manufacture of certain essential inorganic compounds which serve as the starting point for many other processes. Platinum is used as a catalyst in the synthesis of sulphur trioxide (in the contact process for making sulphuric acid) and in the synthesis of ammonia. Other metals and simple inorganic compounds too are used as catalysts for speeding up many reactions.

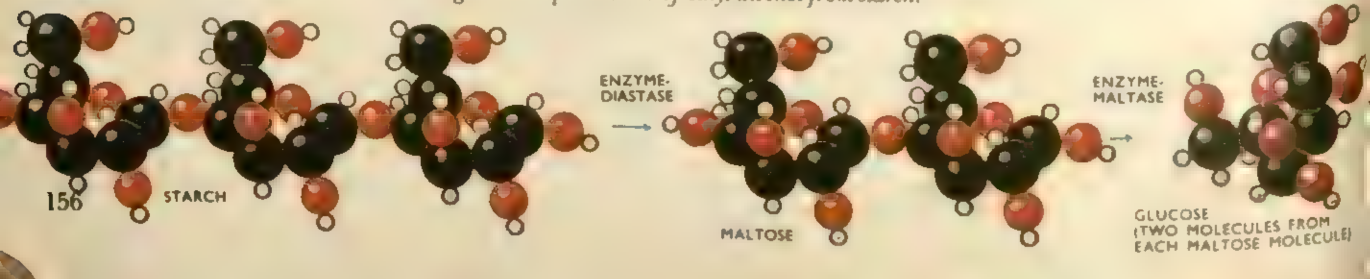
Enzymes are catalysts made by living things. They alter the rates of many reactions that occur in animals and plants. For instance, enzymes play an essential part in the digestive processes which break down foodstuffs into simpler substances. Ptyalin, an enzyme in saliva, assists in the hydrolysis of starch to give sugar.

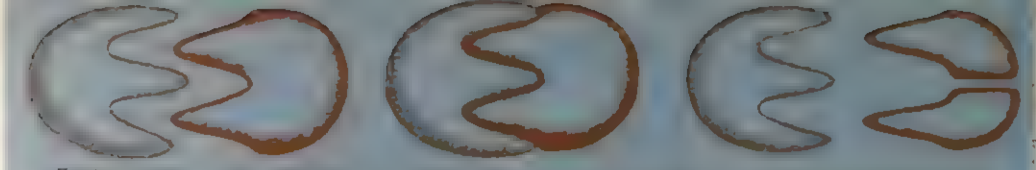
There are, however, certain major differences between enzymes and inorganic catalysts. In the first place, enzymes are complex substances which are produced by living organisms, whereas most of the catalysts used in inorganic chemistry are either elements or simple compounds. In fact, enzymes are so complex that the structures of many of them are not yet known in detail. However, all those that have been separated and purified are proteins.

Another important difference concerns the reactions which the enzymes catalyze. Some of the inorganic catalysts can be used to speed up many different reactions. In contrast, many enzymes are known only to be useful in carrying out one reaction. Others will speed up three or four reactions of the same type.

Some of the simpler chemical reactions which are regularly carried out in living organisms in the presence of enzymes have been repeated in laboratory conditions using more conventional catalysts. For instance, hydrochloric acid may be used to

Stages in the production of ethyl alcohol from starch.





Each enzyme (grey) may be pictured as having a definite shape into which only certain other molecules (red) will fit, like neighbouring pieces in a jigsaw puzzle. The enzyme is able to piece together or to split only the molecules which do fit precisely

hydrolyze (break down by reacting with water) lactose (milk sugar), in place of the enzyme, lactase. However, the reaction goes much faster using lactase than it does with hydrochloric acid. In fact, at 35°C, it takes only an hour to hydrolyze with lactase one quarter of the milk sugar in a 5% solution. In contrast, it takes 5 weeks to get the same effect using dilute hydrochloric acid (2N).

Temperature changes have a much greater effect on reactions using enzymes than on those speeded up by inorganic catalysts. In general the most satisfactory temperature for reactions using enzymes lies in the range 30°C to 40°C. When a reaction is carried out at a higher temperature, the rate of reaction is increased considerably for a short time, but it is then stopped quite suddenly—the catalytic properties of the enzyme and probably the enzyme itself have been destroyed by the heat.

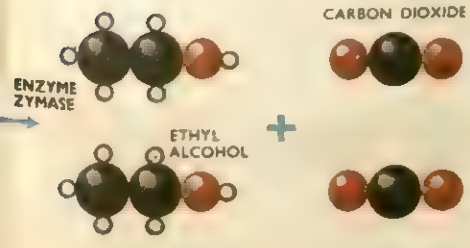
Another factor which affects the catalytic power of enzymes is the acidity (pH) of the reactants. Many enzymes are most effective in approximately neutral solution (i.e. in the range pH 6 to pH 8). There are, however, a number of them which work well outside this range. The enzyme pepsin which is present in the stomachs of vertebrate animals is most effective in strongly acid solution (about pH 2). The acidity is maintained by hydrochloric acid which is secreted with the pepsin in the stomach.

Pepsin helps in breaking down proteins. Other digestive enzymes working further down the food canal break down fats, carbohydrates and proteins. These work in neutral or alkaline solutions. Acids are neutralized by the bile produced by the liver.

Some enzymes aid only single chemical changes so several different enzymes are required to carry out a sequence of reactions. This happens when whisky is made from grain.

The first step is to break down the complex starch molecules in the grain to yield the sugar, maltose. Hot water is added at about 60°C and the mixture left to stand. The enzyme diastase present in malt acts on the starch.

The solution of maltose is then cooled to about 15°C and yeast is added. Yeast contains several enzymes, which are used, in turn, to produce ethyl alcohol. First maltose is hydrolyzed to yield the simpler sugar, glucose (two molecules from each molecule of maltose). The reaction is achieved with the aid of the enzyme maltase. Finally the glucose breaks down into ethyl alcohol and carbon dioxide.



Mineral nutrition in plants

A problem

Our knowledge of plant feeding comes from quite recent discoveries. The history of the investigations which led to their discoveries involves investigation about the nature of air and water.

The following experiment was performed in about 1600 by J. B. van Helmont. Read it critically. van Helmont was trying to find the connection between the water which a plant absorbs and the growth of the plant. (The wording of his account has been altered in places so that you will be able to follow it easily.)

"I took an earthen vessel, in which I put 200 pounds of earth that had been dried in a furnace, which I moistened with rain water, and I planted therein the trunk or stem of a willow tree, weighing 5 pounds. And at length, after five years, the tree weighed 169 pounds and about 3 ounces. When there was need I moistened the vessel with rain water or distilled water.

"The vessel was covered with an iron plate which had holes in it (to allow water in). I did not measure the weight of leaves which fell off each year. At length I again dried the earth from the vessel. It weighed 199 pounds 14 ounces. Therefore 169 minus 5 = 164 pounds of wood bark and roots arose out of water alone."

There is no doubt what van Helmont meant, that is that the 'stuff' of which bark, stem, and roots is made came from the water and nothing else.

If you think van Helmont was wrong, where did he go wrong? How would you explain to van Helmont what he had ignored when he reached his conclusion? What do you think bark, roots and stem are formed from if it is not only water?

Nowadays every gardener knows that plants will not grow well unless they are supplied with certain substances. Thus potash (which contains potassium) is a valuable 'food' for crops such as potatoes and for good fruit production. Plants in soils that are short of phosphorus grow slowly and their leaves are often tinged with red. Clover, too, does not grow well in phosphorus-deficient grassland. By adding nitrogen to the soil in the form of nitrates, plant growth may be greatly increased and the yellowish

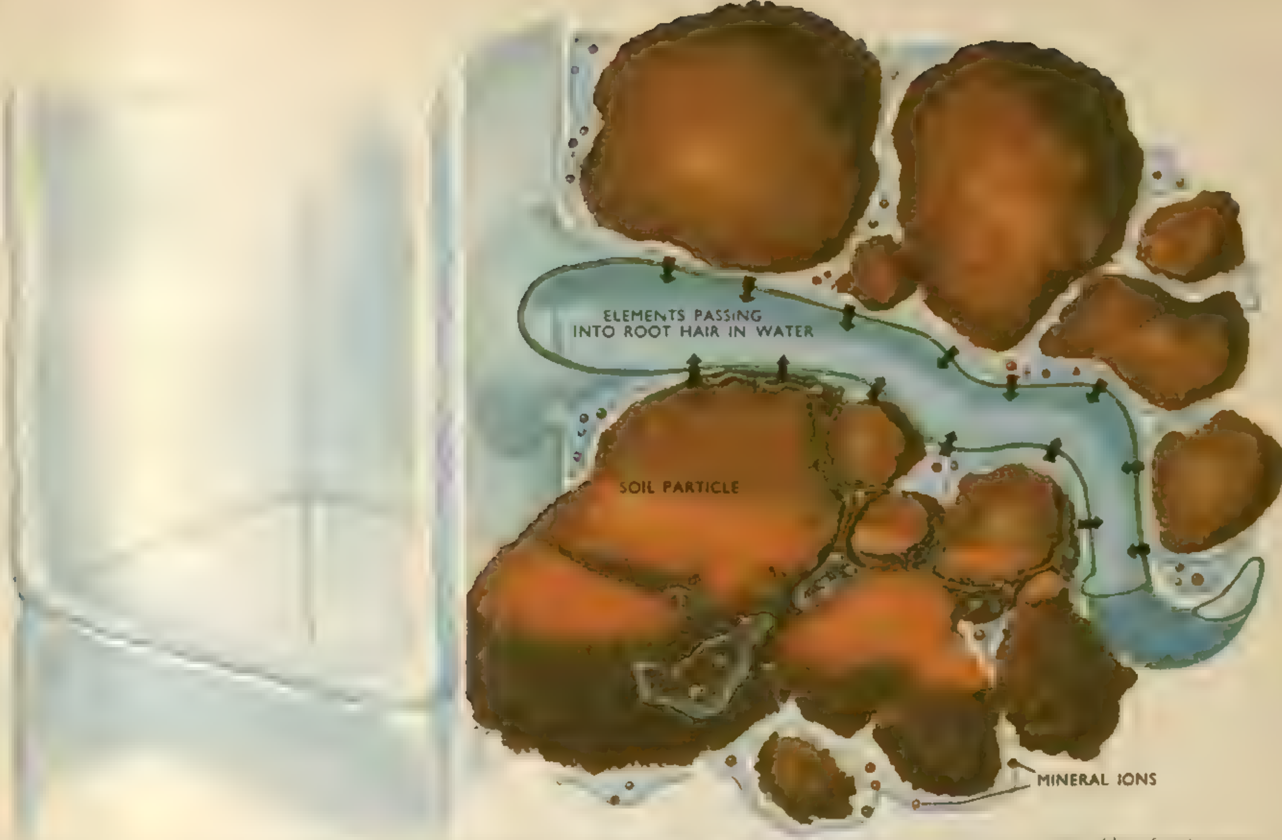
leaves become dark green (providing no other necessary element is missing).

The plant body consists mainly of carbon, hydrogen, oxygen and nitrogen. Nearly all the carbon and oxygen is obtained from the carbon dioxide in the surrounding atmosphere and most of the hydrogen is obtained from the water absorbed by the roots. Nitrogen is absorbed through the roots as 'nitrate' dissolved in the soil water.

If a plant is burnt and the ash that remains is analysed it will be found to contain several other elements, namely iron, magnesium, aluminium, calcium, potassium, sodium, silicon, phosphorus, sulphur and chlorine. The proportions of these vary considerably and not all of them are essential for the healthy growth of the plant. For example, though sodium and chlorine are present in considerable quantities, they have not been shown to be essential. The ones that are essential can be shown by growing the plants in special water cultures. Plants are grown in jars containing carefully balanced quantities of certain salts dissolved in water. Some of the jars contain all of the necessary elements and each of the others lacks one different element. The plants supplied with all the elements grow healthily, while some of the others appear yellow or stunted, showing that the elements missing from these jars are necessary for healthy growth. Six elements are essential in relatively large amounts besides carbon, hydrogen, oxygen and nitrogen. These are calcium, iron, magnesium, phosphorus, potassium and sulphur. Other substances are also needed, but only in the minutest quantities. These are the so-called trace elements – manganese, boron, zinc, copper and, in some plants, molybdenum. They are supplied in the water cultures, for the salts used in this experiment usually contain them as impurities.

Apart from most of the carbon and oxygen, the plant absorbs the elements it requires in solution from the reservoir of minerals in the soil. Usually these are not present as molecules but as ions in solution in the soil water. Each soil particle holds

A series of bottles with seedlings growing in them. One bottle contains all the elements necessary for healthy growth, the others each lack one different essential element and the plants in them show obvious signs of ill-health. Each bottle contains the trace elements.



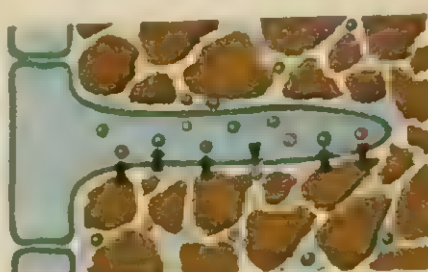
A diagram of a highly magnified root hair cell showing its relation with the soil particles. These may have a covering film of water over their surfaces. The elements are shown as ions in solution in the soil water and passing into the root hair.

a thin film of water round it. This film contains ions which are also present in decaying material (humus) and also in any water which lies freely in the soil (i.e. not attached to soil particles).

Though the minerals enter the root hairs in solution, there is no relationship between the quantities of water absorbed and the quantities of minerals taken in. Water passes into the root cells by osmosis, but exactly how minerals pass into the root is at present not clear. The rate at which they are taken up from the soil may vary considerably. Some elements enter the root much more easily than others. Also their concentrations in the root may be much higher than those in the soil so that work has to be done (i.e. energy expended) to obtain them. The energy for the uptake of minerals comes from respiration (i.e. the food-oxidizing processes which take place in the cells of the root). The 'fuel' consumed in respiration is usually a sugar or similar compound and this will either have been formed in the plant's food-building processes (photosynthesis) in the leaves or formed from one of the products of photosynthesis. Respiration usually requires oxygen, and so it is important that the soil round the roots has plenty of air spaces in it to allow oxygen to pass into it from the atmosphere.

After the minerals have entered the root hair they will pass from cell to cell. Some may be used up by the growing cells in the centre of the root and others will be carried to the upper parts of the plant in the stream of water (transpiration stream) being pulled upwards to replace that evaporated from the leaves by the sun. Any cells near the water-conduct-

When the ions of some elements (e.g. calcium, potassium, magnesium) enter the root hair in solution from the soil the ions of one or more elements may pass out in exchange to help maintain the correct proportions of ions with positive and negative charges in the root hair.



The importance of ions

Copper will not dissolve in water. Copper sulphate contains copper yet will dissolve completely in water. Copper sulphate, like any salt, is made up of incomplete atoms called ions. A copper ion in copper sulphate is an atom which has lost two of its outer electrons and is therefore positively charged. An ion behaves quite differently from a complete atom of the same metal.

One important factor in determining the ease with which elements enter the plant is the size of the ions of these elements. In a watery solution each ion obtains a 'coating' of water (each is said to be *hydrated*). The larger hydrated ions pass less easily into the root. Sodium, for example, does not enter the root so rapidly as potassium. The rate at which various ions enter will also depend on their concentration in the soil and on the proportions of other ions present.

The water culture experiments reveal that when some elements are absent from a plant's 'diet' the growth of the plant is seriously affected.

NITROGEN

Nitrogen is of utmost importance. It may account for as much as 4 per cent of the plant's dry weight (i.e. its weight minus that of the water it contains). The majority of plants rely on the nitrogen in the soil for their supply and it is absorbed by the roots in the form of nitrate or in the ammonium part of an ammonium salt. The nitrogen absorbed is rapidly used up and is eventually built up into the complicated molecules called amino acids and proteins. These form the main part of the plant's protoplasm (proteins and amino acids are compounds whose molecules contain carbon, hydrogen, oxygen and nitrogen atoms and sometimes sulphur and phosphorus atoms as well). If nitrogen is lacking from the plant's diet it is unable to build up amino acids or proteins, since the latter are formed by the joining together of amino acid molecules. A seedling will never reach a very large size—it will be able to grow for a time using the stores of nitrogen in the seed—and will eventually die.

MAGNESIUM

Magnesium is part of the chlorophyll molecule. If it is lacking no chlorophyll can be formed, although the plant will be able to grow using the food stored in the seed. It will lack any green pigment (a condition called *chlorosis*) and it will produce seeds of a poor quality and which are few in number.

IRON

Though *iron* is not itself part of the chlorophyll molecule it is necessary for the formation of chlorophyll. Lack of iron causes the young leaves of the seedling to appear a creamy white due to the absence of the chemical reactions within the living cells of the plant.

POTASSIUM

The results of *potassium* deficiency vary considerably as the amounts of other elements vary. If ample supplies of nitrogen and phosphorus are present new growth is not usually slowed down by the absence of potassium, but the older parts (particularly the leaves) tend to become yellow and die. This affects the plant's food-making capabilities and fruit and seed production are seriously interfered with.

PHOSPHORUS

Phosphorus plays a vital role in the plant's chemistry. It forms part of the complicated protein molecules in the cell nuclei and it is present in fatty substances and combined with sugar molecules. Many of these phosphate-containing molecules are important because energy for use in respiration and other processes is released when these molecules split. The leaves of plants unable to obtain sufficient phosphorus die off rapidly and the mature plant ripens very slowly. Growth in general is slowed down considerably.

SULPHUR

Sulphur is a constituent of many amino acids and proteins. Lack of it produces stunted growth and the colour of the plant is pale.

CALCIUM

If *calcium* is lacking, growth is stunted and the quantity of chlorophyll in the leaves is lowered. Growth of the root and shoot of the seedling is soon brought to a halt. Calcium acts as building material, for it is present in calcium pectate which acts as a cementing substance, binding together the cell walls of adjacent cells.

TRACE ELEMENTS

The exact role of the *trace elements* is not well understood at the present time, but when they are absent from a plant's diet they may cause serious diseases. It would seem that some trace elements must be present in the cells to enable enzymes to perform their everyday tasks of piecing molecules together or splitting them. Others appear to be an essential part of the enzyme molecules. *Boron* is necessary in order that the plant can obtain and use calcium in an efficient way. Plants, such as clover, have swellings on their roots in which bacteria live. The bacteria are able to convert nitrogen gas from the atmosphere into nitrates. This process requires the element *molybdenum* and is unable to take place in its absence. *Manganese* occurs in at least one enzyme and its presence is needed for certain other enzymes to work. Zinc has a similar role with the same enzymes. *Copper*, like iron, may be necessary for the formation of chlorophyll and is essential to some enzymes that oxidize (add oxygen to) the substances in the living cells.

ing channels will be able to build up a 'stock' of minerals very quickly (if chemical reactions are proceeding rapidly in them).

Most of our knowledge of mineral nutrition has come from water culture and other experiments in the laboratory. However, we have also discovered many facts from farming. The failure of crops to grow in certain areas due to the absence of some elements from the soil, and a gradual fall in the yield due to over-intensive farming and thus exhausting the soil, are two examples.

In some parts of the world lack of trace elements has seriously affected the growth of fruit trees and crops. Orange trees in California suffer naturally from a lack of zinc, and 'grey speck' of oats, particularly prevalent in fen country, is due to manganese deficiency. Many of the crops grown on land reclaimed from the sea in Holland suffered from copper deficiency.

Crops without soil

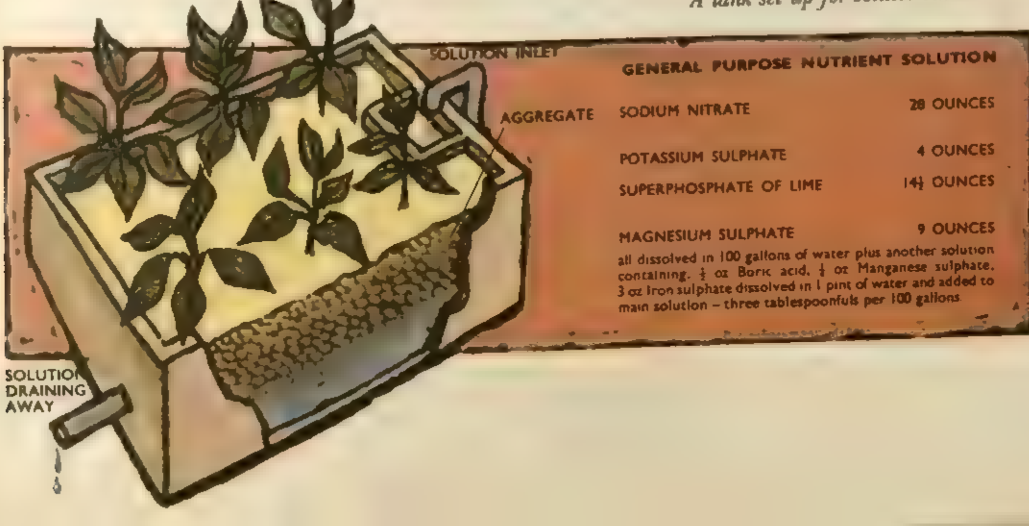
More than two hundred and fifty years ago the first recorded attempt was made to grow plants solely in a liquid medium. In 1804 a Swiss, de Saussure, carried out more controlled experiments, culturing plants in dilute solutions of various salts. Amongst other things, he showed that a plant is able to absorb the salts it requires from very dilute solutions. From these early beginnings the science of *hydroponics* has emerged. Hydroponics is the growing of plants in solutions of pure chemicals.

In the first place hydroponic methods were confined solely to the laboratory. Today, water culture methods are still an important research tool but they also have commercial application. Some tomatoes and cucumbers, for example, are grown by hydroponic methods. Moreover, purely hydroponic techniques have been superseded by others in which the plants are provided with a medium to root in—sand, gravel and vermiculite are commonly used. The rooting material may be supplied with solid fertilizer which is washed in with water, or with liquid fertilizer containing the necessary salts in the correct proportion. A more advanced method—the sub-irrigation system—involves flooding the rooting material (aggregate) by pumping in a nutrient liquid at preset intervals. Surplus solution drains back very slowly, by gravity, into large storage tanks and is then available for recirculation. Disadvantages of this method are mainly that the strength of the solution decreases gradually with each application, and, more serious, the proportions of the salts dissolved in it may change. Analysis of this is tricky and requires careful and skilful estimation, for many of the required nutrients are present only in minute quantities. Such elements as molybdenum, manganese, copper, boron and zinc are needed in amounts less than one part per million in solution. Some substances must be added from time to time to maintain the correct proportions of mineral salts.

However, soilless cultivation has several advantages over normal horticultural methods (though the reverse is also true). The plants can be fed so much more intensively that more can be cultivated in a given area and thus greater yields are obtained than with plants grown in soil in the ordinary way. The feeding can be related to an aggregate whose physical properties are known and which remain relatively constant.

The soil is an ever changing environment responding both to mechanical and physical factors, such as rainfall, temperature, the drying effects of sun and wind, and the living population. Its organic content (i.e. decaying animal and plant matter) is continually changing, as it is broken down by bacterial and other activity and as the growing plants use up nutrients. The results of applying nutrients and other substances are less predictable, therefore, and soil-borne pests are less easily controlled.

A tank set up for soilless culture.



Where overhead watering is employed it is best to use an aggregate that dries out slowly. Clean sand of medium grain size is most suitable, whereas for sub-irrigation techniques a coarser aggregate, such as gravel, is needed.

The composition of the nutrient solution and how often it is applied will vary with the requirements of different plants and also with the season and local weather conditions. A high phosphate level encourages the early ripening of many crops. Tomatoes are responsive at different times of the year to varying proportions of the three major plant nutrients—potassium, nitrogen, phosphorus—and so the dosage is varied to produce the maximum yield.

Fertilizers

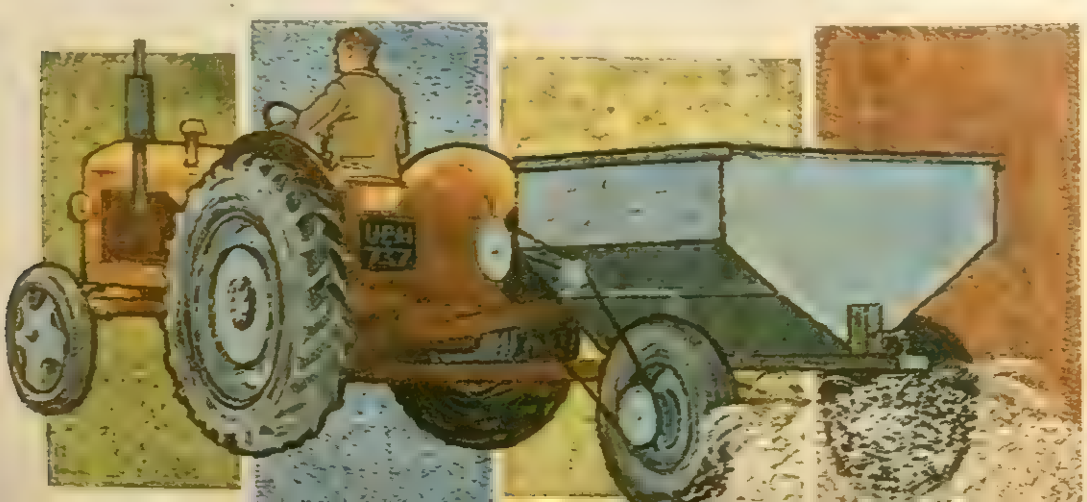
For several thousand years man has added manure and compost to the soil in order to grow healthy crops and to increase the yield. But it is only in recent years that our knowledge of plant chemistry has been sufficient for us to understand what makes a plant grow—and, therefore, why manuring is beneficial to the plant.

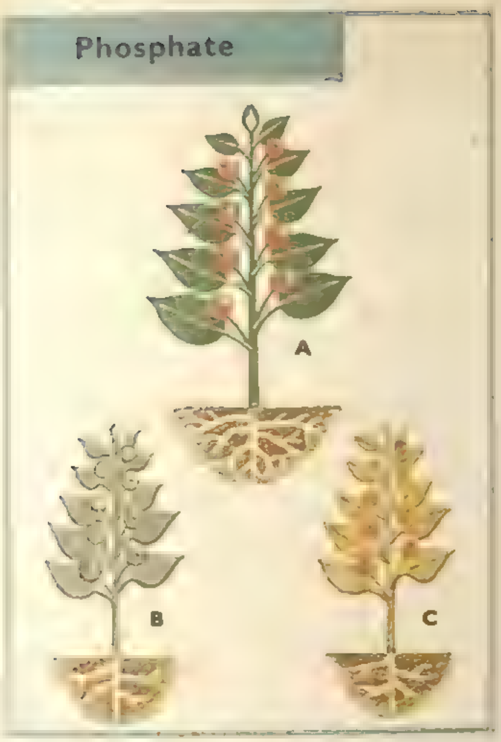
The amount of available farmyard manure is only a fraction of the total required to maintain crop yields at their present level and, to maintain the proper level of soil organic matter, it must be supplemented by the use of fertilizers. The chemists of the nineteenth century deduced that a small quantity of fertilizer supplies the amount of plant food present in a ton of farmyard manure. So they started to look for mineral salts that contain the elements needed by plants. Chile saltpetre (sodium nitrate) had been used for some time, as had ammonium sulphate. The former occurs in vast deposits in Chile, and sulphate of ammonia was becoming available in larger quantities as a by-product of the coal gas industry which was expanding rapidly.

(a) Nitrogen encourages rapid leaf growth. (b) Insufficient nitrogen means poor, weak growth. (c) Excessive nitrogen can cause soft rank growth.

However, the fertilizer industry was really established after John Lawes, a Hertfordshire landowner, discovered that bone dissolved in sulphuric acid had a beneficial effect on plant growth. Bone is rich in calcium phosphate and at the time large quantities of this chemical were found in Germany. In 1842

Granular fertilizer being distributed by a spinning type of spreader.





(a) Phosphate is essential for root development and early maturity. (b) Growth is slow and restricted without sufficient phosphate. (c) Massive phosphate dressings can induce early ripening.

(a) Potash encourages healthy growth and increases resistance to drought, disease and extremes of temperature. (b) With too little potash, leaves may be scorched and plants stunted and disease prone. (c) Large unbalanced potash dressings upset mineral nutrition.

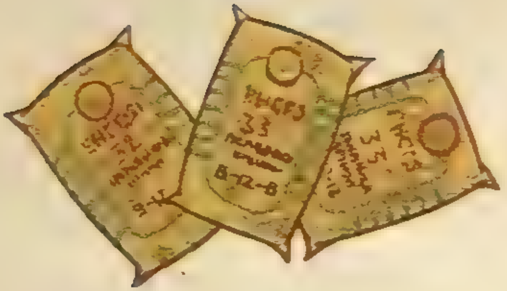
Lawes set up a factory for the production of treated calcium phosphate or superphosphate as it was called.

For many years superphosphate was the only fertilizer manufactured, but the present century has seen the development of a bewildering range of artificial plant foods. Besides these inorganic plant foods, organic fertilizers have been developed. The application of these, together with the practice of ploughing-in green crops and straw, helps to maintain a sufficient level of soil organic matter. Due to their high cost of manufacture, organics are almost exclusively used in horticulture, especially by market gardeners.

Fertilizers are essential for maximum crop production. They are not substitutes for farmyard manure or compost but should be used in conjunction with the latter. Most soils have a natural reserve of plant nutrients, but adequate amounts of these are rarely present. Fertilizers supplement the natural supply. The modern practice is to apply fertilizer dressings that contain the three most essential plant foods, nitrogen, phosphorus and potassium, in properly balanced amounts. A soil so supplied, and also provided with humus and lime, will satisfy the main requirements of the crops. The continued application of one plant food only is not sufficient, and the yields will become lower and lower.

Nitrogen increases the green colour of leaves, their size, rate of growth and final yields. It is the main plant food for leafy crops such as cereals and greenstuffs. Application to grassland in the correct quantities promotes lush growth and extends the grazing season. However, excessive application of fertilizers rich in nitrogen may cause overgrowth of the plants which are then particularly susceptible to disease.

Fertilizers containing phosphorus stimulate root development and are particularly effective on heavy soils. Phosphorus is the dominant food for most root crops and it encourages the development of root nodules on peas, clover and other leguminous crops. By inducing the early ripening of a crop, especially cereals, it enables good harvests to be obtained in wet areas and reduces the chance of the crop being spoiled by the weather. Usually phosphate fertili-



Fertilizers are of two main types, *organic*, that is derived from animal and plant residues or waste products, and *inorganic*. Inorganic fertilizers may be synthetic (e.g. sulphate of ammonia) or 'natural', e.g. potash, which is used in the same form as it is mined. Superphosphate is an example of a fertilizer formed by chemical treatment of a naturally occurring mineral (phosphate rock). Some organic fertilizers (e.g. dried blood) supply only nitrogen (12-15%) while others supply nitrogen and phosphate (e.g. bone meal—about 4%N, 22% insoluble P_2O_5).The same applies to inorganic fertilizers. Sulphate of ammonia supplies nitrogen only (20·8%), and nitrate of potash supplies both nitrogen and potassium (15%N, 10% K_2O). 'Rock Phosphate' and superphosphate supply phosphate only, respectively 27%-33% P_2O_5 and 16%-20% P_2O_5), though the former is insoluble and the latter soluble in water. Sulphate of potash supplies potassium, only (48% K_2O).

Nowadays many compound fertilizers are sold. These supply several 'single' fertilizers thoroughly mixed together and blended in known quantities. The use of compound fertilizers avoids the separate application of single fertilizers, a great saving in time and money.

Most fertilizers are available in a granular form as well as powder. The granular condition is essential for even distribution.

A practical problem

Seeds contain supplies of reserve starch in their cotyledons. Starch is not soluble. Insoluble substances cannot be transported. Insoluble stacch may be converted to sugar by enzymes.

Do broad bean seed embryos produce an enzyme which can turn starch to sugar?

Set out on paper your ideas as to how you could show by experiment (a) that an extract of embryos contains a substance which can change starch; (b) that this substance is an enzyme.

zers are applied to the soil when the seeds are drilled. The latter thus have a readily available supply of phosphorus from the time that they germinate.

Potassium encourages healthy plant growth. It plays an important part in the uptake and utilisation of water, increasing a crop's resistance to drought and reducing the effect of extremes of temperature. It is also concerned with the manufacture of sugars and starch so that its application, as potash, to crops such as potatoes, peas, beans and tomatoes, is particularly effective. Potassium-containing fertilizers dissolve readily in water, but the potash is held by the soil particles and leaching occurs only in very light, sandy soil. Light sandy and chalky soils are the most likely to be deficient as they have no natural potash reserve. Excessive application of potassium fertilizers on their own must be avoided, for this may accentuate such abnormalities as magnesium deficiency.

Because the requirements of different soils and the needs of different plants vary, a number of fertilizers of widely differing chemical composition are available. The gardener and farmer must be able to see at a glance what each contains. A convenient method of expressing the plant food value of a fertilizer is in terms of Nitrogen (N), Phosphoric acid (P_2O_5) and Potash (K_2O). By law, each fertilizer sold must have a guarantee of its plant food value expressed in terms of N, P_2O_5 and K_2O. Thus sulphate of ammonia is sold as containing 20·8% nitrogen (ammonium, NH_4, contains nitrogen) and nitrate of soda contains 16% nitrogen.

Photosynthesis

An animal eats either plants or other animals. The animals that a flesh-eating animal consumes may themselves be flesh-eating but in every food chain there comes a point where a green plant has been eaten. Even when we eat bread we are eating food that has been prepared from a plant. Indeed 'all flesh is grass'. The green plant is the mainstay of the living world.

Our food not only supplies the molecules which our bodies can piece together to build up muscle,

The combine drill places the fertilizer close to the seed.

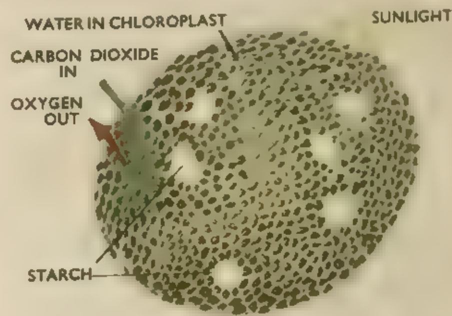
bone etc., it also supplies us with the energy needed to perform these tasks, to repair worn or damaged organs, to enable us to breathe, to move about and so on.

When an animal eats a plant the energy it obtains has originally come from sunlight. The basic source of all food is the remarkable process called photosynthesis, occurring in all green plants that possess the mixture of pigments called chlorophyll. The raw materials of photosynthesis are pieced together using the energy of sunlight so that the products of the process incorporate some of this energy store which can be used by the plant in its other processes (the only plants able to make their own food apart from green plants are some bacteria).

This dependence of other living things upon the green plant is illustrated very clearly by comparing the numbers of floating and drifting plants (phytoplankton) and animals (zooplankton) in the Atlantic Ocean over the year. From the graph you will see that a rise in the numbers of green plants in the spring is followed by a rapid rise in the numbers of animals. These graze on the plants (which exhaust the supply of minerals) so that the numbers of the latter drop quickly, followed by a drop in the number of animals since they have little plant food left to feed on. When there is a further brief rise in the plant population in the autumn there is also a rise in the animal population, which again rapidly reduces the number of plants down to a low level. So the animal numbers drop off once again when the food supply becomes scarce.

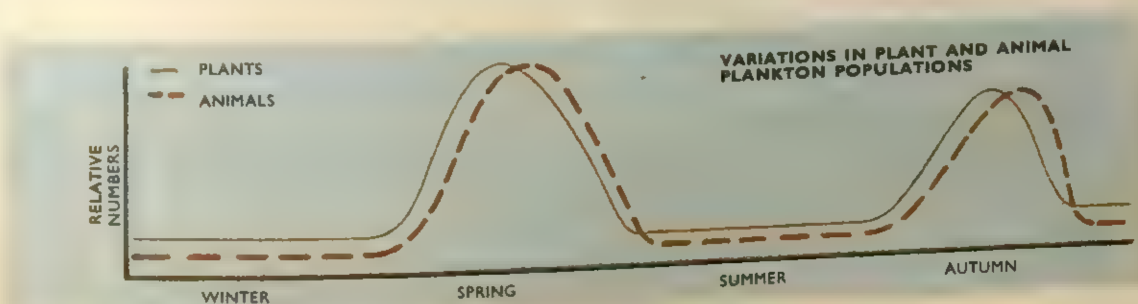
Photosynthesis (*photos*, light; *synthesis*, building), or carbon assimilation as it is also called, is the process in which the green plant builds up sugars, starch and other compounds from carbon dioxide and water using the energy of sunlight. The plant obtains its carbon dioxide from the air and the water is taken in from the soil through the roots. Most photosynthesis takes place in the leaves. It is here in the cells which possess the chlorophyll-containing bodies—*chloroplasts*—that the atoms of carbon dioxide and water are rearranged, so that sugars are formed after a complicated series of chemical reactions have taken place. The energy for part of this chain of reactions comes from sunlight having been trapped by the chlorophyll and then handed on from this to other chemical compounds.

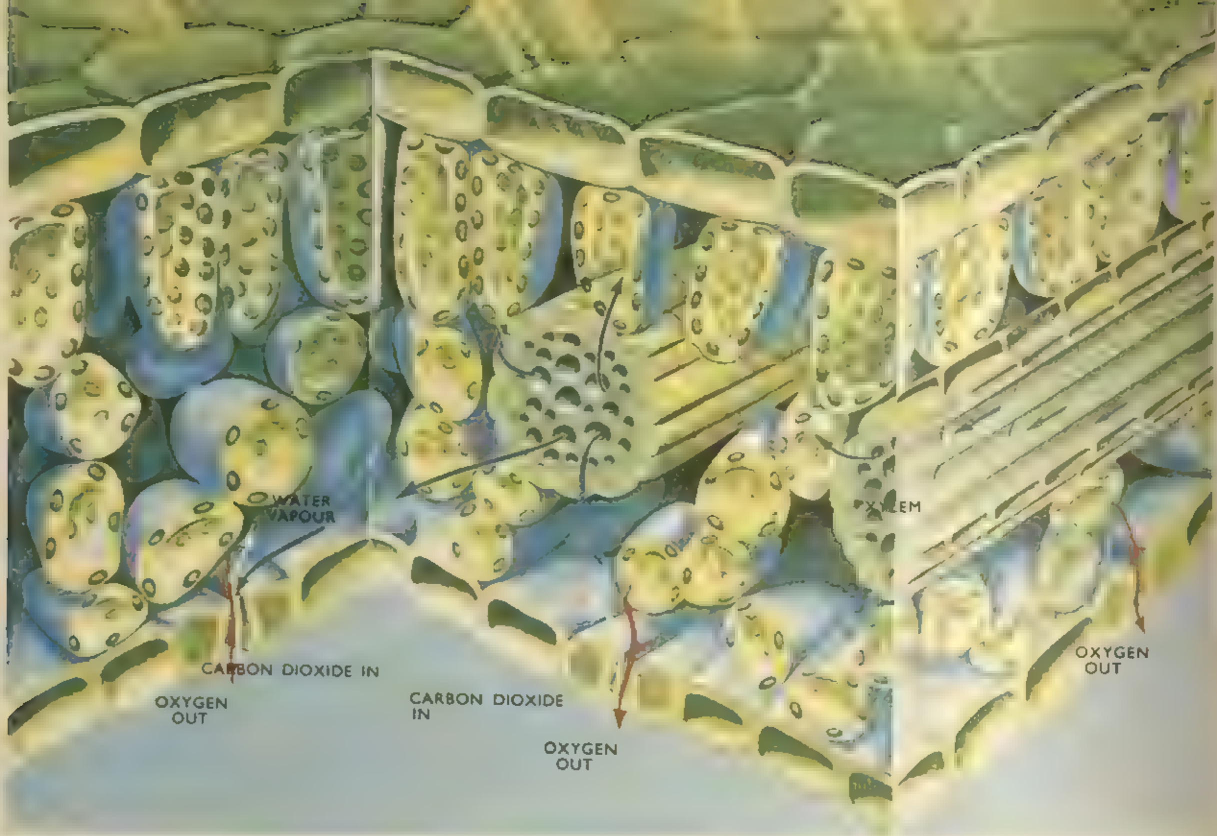
The amount of carbon dioxide in the lower atmosphere is only about 3 parts in 10,000 of air. It is calculated that each year the green plants consume over $\frac{1}{30}$ of this amount, so that in just under thirty years all the carbon dioxide would be used up unless it were replaced. In fact the percentage of carbon dioxide in the air remains approximately the same from year to year. Carbon dioxide is released by both plants and animals in the 'food-oxidizing processes' which take place within their cells. Considerable quantities are also released from fires and by the minute organisms in the soil that are responsible for decomposing dead animal and plant remains.



A diagram of a chloroplast summarising its role in photosynthesis.

Carbon dioxide enters the leaves of the plant mainly through the tiny pores in the leaf skin. These stomata, as they are called, are usually found mainly in the skin of the lower side of the leaf. Many of the cells inside the leaf skin have air spaces between them. The cells themselves have a layer of protoplasm lining the inside of the cell wall and inside this is a watery fluid, the cell sap. The protoplasm





A block diagram of part of a leaf showing the entry of carbon dioxide through the stomata and its passage into the leaf cells. Oxygen produced in photosynthesis passes out of the leaf pores. Water (blue arrows) is shown passing from the water-conducting channels (xylem) into the leaf cells. Some of it takes part with the carbon dioxide in photosynthesis while much of it passes out of the leaf pores as water vapour evaporated by the sunlight.

contains the chlorophyll-containing bodies (chloroplasts). Before it can take part in photosynthesis the carbon dioxide has to make its way to the chloroplasts, since photosynthesis can only take place in the presence of chlorophyll. The leaf cells adjacent to air spaces have a thin film of water over their free surfaces and the carbon dioxide which has entered the leaf through the stomata dissolves in the watery film (this water has reached the leaves from the roots in the transpiration stream, the column of water which is pulled up the stem of the plant to the leaves due to the evaporation of water from them by the sun).

In solution the carbon dioxide can pass through the water-laden walls of the leaf cells into the chloroplasts, which themselves are in the watery protoplasm.

The leaf skin is transparent. Most of the sunlight which falls on the leaf is able to pass through the skin, though only a small proportion of the light absorbed by the leaf falls on the chlorophyll and is actually taken up by it and used in photosynthesis. However, chlorophyll does absorb most of the light that falls on it. This is of tremendous importance to the plant, for it absorbs a much greater proportion of the light which falls on it than do the other constituents of the leaf (e.g. water, carbon dioxide, etc.). Not only does it absorb light energy but it is also able to hand on at least part of this energy to other chemical substances in the leaf. These are unable to obtain light energy directly. Substances that absorb light energy and pass some of it on to others are called photosensitizers. A practical example is the dye incorporated in certain photographic films. Visible light will change the silver bromide into silver and bromine on an ordinary black and white film. But infra-red rays (heat) will not produce the desired result unless a special dye (a photosensitizer) is added to the silver bromide.

The amount of chlorophyll in the leaf does not change as photosynthesis proceeds. It enables the

reaction to proceed but it can be recovered intact after the reaction has taken place (i.e. it is a catalyst).

The net result of photosynthesis in the chloroplasts is that the atoms of the carbon dioxide and some atoms of the water molecules are pieced together, using the energy of sunlight which is passed on to some of the substances taking part, to form sugar and oxygen. The oxygen is given off as gas bubbles into the air spaces of the leaf and passes out of the stomata into the atmosphere. If on a bright day you look at the surface of a pond in which pondweed is growing you will see numerous tiny bubbles rising to the surface. These bubbles contain oxygen gas that has escaped from the leaves of the pondweed and which has been produced as a result of photosynthesis.

Though we summarise photosynthesis by saying that carbon dioxide plus water and energy yield sugar and oxygen according to the equation:

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \text{Energy} \rightarrow \underset{\text{glucose sugar}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

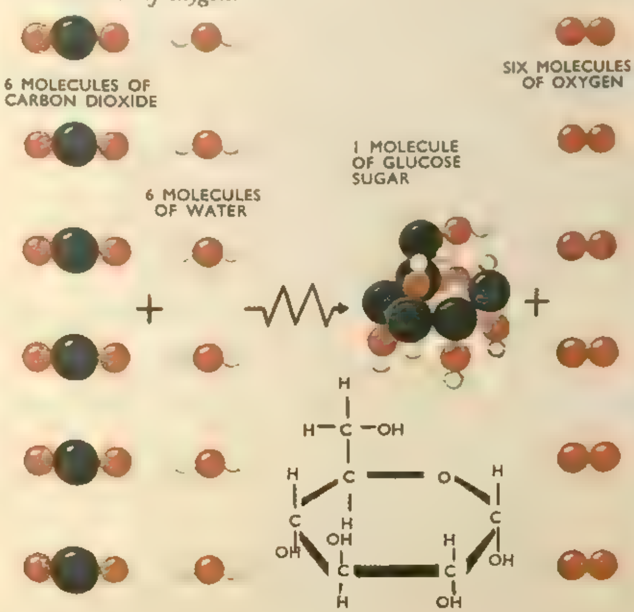
this is really an over-simplification; for photosynthesis is not just one simple reaction, it is a very complicated series—a chain, maybe several chains of chemical reactions, of which carbon dioxide and water form the starting point and oxygen and sugar form the end point (each reaction is controlled by an enzyme). Though we know some of the intermediate chemical substances that are formed, these may be only a few of the many intermediates that undoubtedly exist. Even though reactions are shown to take place in the test tube under laboratory conditions, this does not prove that the same reactions take place in the living plant cells in the leaf.

We are fairly certain, however, that in one of the chemical reactions oxygen is split off from the water molecule and is given off by the plant. It is this reaction which requires light, and the energy released by it is incorporated into chemical substances which then undergo many further reactions and which can proceed in the dark to produce the food materials needed by the plant.

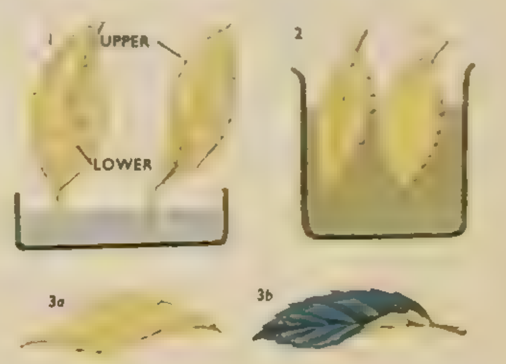
Though carbon dioxide and water are the basic raw materials of photosynthesis some mineral salts are also necessary. The chlorophyll molecules each contain an atom of magnesium. If magnesium is lacking from a plant's diet the plant becomes yellow and is unable to form any chlorophyll, it cannot photosynthesise and so may eventually die. Iron, too, is necessary in small quantities for the formation of chlorophyll though it is not part of the chlorophyll molecule. Lack of iron also causes the green plant to become yellow.

The speed at which photosynthesis occurs de-

Photosynthesis—*six molecules of carbon dioxide together with six molecules of water produce one molecule of glucose sugar (shown in two different ways) and six molecules of oxygen.*



Two leaves are removed from a destarched plant. The upper side of one and the lower side of the other is greased with Vaseline. The stalks of each are dipped in water (1) *and the leaves are left in light for four hours. Most of the Vaseline is wiped off and* (2) *the leaves are now placed in boiling alcohol to remove chlorophyll. The leaves are placed in a solution of iodine in potassium iodide. The plant greased on the upper side develops a blue colour* (3b), *showing that starch has formed from carbon dioxide which was able to enter through the leaf pores. No colour develops in the other leaf* (3a) *in which the pores (these are mainly on the underside) were blocked.*



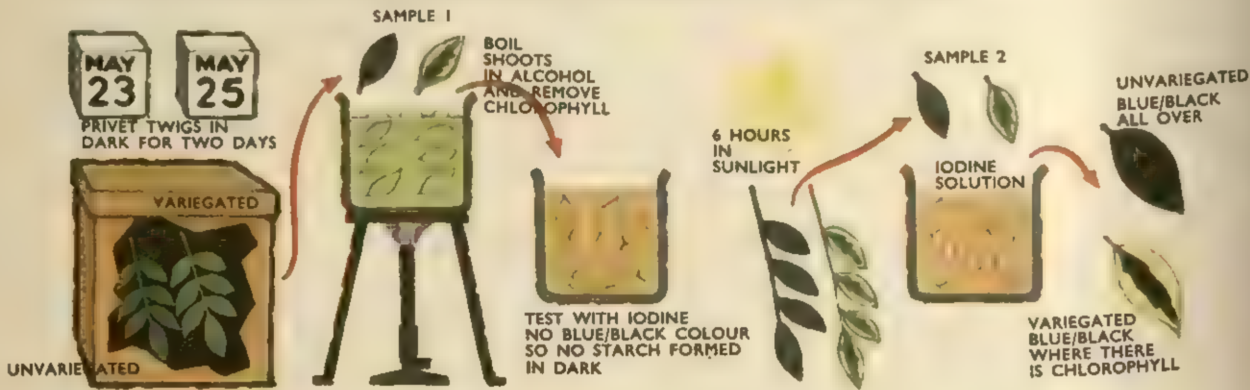
(1) The leaf of a plant is covered with dark paper for two days so that no light falls on it. This destarches the leaf. (2) A cross is then cut in the paper so that this area will then receive light (a period of about four hours is sufficient). The leaf is then removed, placed in boiling water and then in alcohol to extract the chlorophyll. After wetting in water it is placed (3) in a solution of iodine in potassium iodide, washed and (4) a dark blue cross develops where starch has been formed inside, showing that it was formed only in the part of the leaf exposed to the light.

pends on a number of factors, such as the amount of carbon dioxide that enters the plant, the light intensity, the amount of chlorophyll in the chloroplasts, and the temperature. If any one of these increases it may cause an increase in the rate at which photosynthesis takes place, though the effect of each factor will always depend on the others—if the light intensity is too high, for example, photosynthesis will stop, so that an increase in the other factors will not cause photosynthesis to resume.

Photosynthesis also depends on the opening and closing of the stomata. These are generally open during the day and closed at night. However, when the plant has lost an excessive amount of moisture, during a long, dry spell, for example, the stomata may open only for a short time or not at all so that the amount of carbon dioxide which can enter the leaf is severely restricted, perhaps reduced to zero. This means that photosynthesis is restricted or prevented.

PROBLEMS

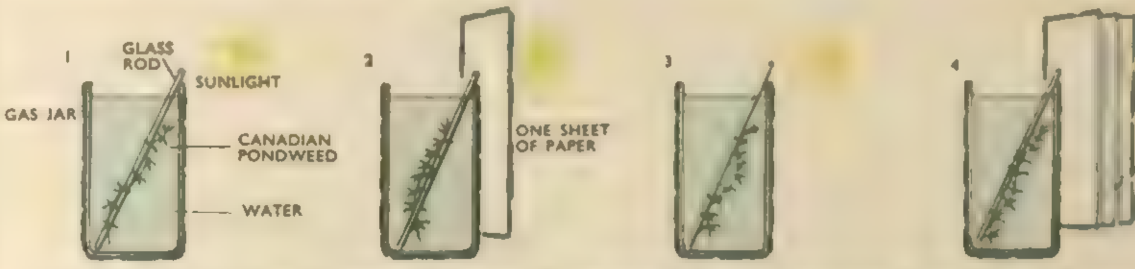
1. A geranium leaf has been found to contain starch after a period in light. The starch might have been made in the leaf or transported to the leaf from the stem. Leaves collected after a period in darkness do not contain starch How would you set up an experiment to find out if the starch was made in the leaf or transported to the leaf?



2. Two branches of privet, one with golden (variegated) leaves, one with green leaves, were kept in the dark for two days. Two or three leaves (sample 1) were removed from each twig, decolourised in boiling alcohol and tested for starch with iodine solution. The twigs were now exposed to bright sunlight for 6 hours. Three more leaves (sample 2) were removed and tested from each twig as before. The results are illustrated, showing the leaves before decolourising and after decolourising and testing.
   Study the results and answer the questions
   a. How can you account for the fact that starch is present in the second sample of leaves?
   b. How can you account for the results for sample number 1?
   c. What is the connection between the distribution of chlorophyll and any other fact evident in these results?
   d. Could the following explanations of these results be correct (from this evidence alone)?—
   "Starch is not made in leaves, it is transported there during daylight. It is only transported to those areas which contain chlorophyll. During darkness starch is transported away from the leaf."

3 If light is passed through a prism it is split up into all the colours of the rainbow. If light is passed through a solution of chlorophyll and then through a prism – the rainbow looks like this

Now, it has been found that in red light and blue light the manufacture of starch is much greater than with light of other colours. Invent a theory to explain this connection.



4. Set up a strand of Canadian pondweed – as shown in the diagram – on a bright sunny day. Break the stem at one point. Bubbles will rise to the surface. (If they don't set up another strand of weed.)
   Count the bubbles rising per minute.
   Now place a sheet of white paper between the sun and the jar – count the new rate of bubbling.
   Remove the paper and again find bubbling rate. Repeat with 2 sheets of paper – then no paper – then 3 and so on.
   Record temperatures during this experiment. Plot a graph – no. of sheets of paper against rate of bubbling.
5. Set up a strand of pondweed as in (4). Find rate of bubbling at constant light intensity. Now add ½ a teaspoonful of sodium bicarbonate (for each litre of water). Find the new bubbling rate.
   List what these two experiments have shown. What is the connection between the appearance of gases as bubbles of gas, and the manufacture of starch?
6. Collect gases given off by pondweed and find out how much oxygen is present. For technique see p. 70 (inspired air analysis in animal physiology section).
7. In the nutrient solution described in the section on crops without soil carbon-containing compounds may be omitted. The plants grow successfully. Plants contain starch, cellulose, sugars, proteins and fats, all of which contain carbon. How can you explain this?
8. Although we may suspect that sugar, which contains carbon, is made from carbon dioxide gas from the air, we need experimental evidence to support the theory. Radioactive substances often prove very useful in tracing chemical pathways. Use the following facts and try to design a simple experiment to answer the question, is sugar made from carbon dioxide?
   a. Radioactivity can be detected by the use of an instrument called a Geiger counter.
   b. Radioactive carbon dioxide $C^{14}O_2$ (the carbon is the radioactive part) can be obtained by adding acid to radioactive barium carbonate.
   c. Sugar can be extracted from leaves.
   d. Whenever radioactive carbon is used to make a compound, the compound is radioactive and remains so as long as it contains the radioactive carbon, e.g. radioactive carbon dioxide added to lime water would give radioactive chalk.

How plant cells use food

We have described previously how the plant builds up sugars and starch from carbon dioxide and water in photosynthesis, how it takes in water and how it takes in minerals in solution from the soil through its roots. Having obtained or having made these substances what is their fate inside the plant?

The substances formed in photosynthesis (sugars, starch, etc.) only remain in the chloroplasts (the chlorophyll-containing bodies) for a short time after they have been formed. If the end-product is starch, for instance, it will be deposited temporarily in the chloroplasts. Starch is insoluble (it does not dissolve in water) so that its presence in the chloroplasts will not interfere with other processes. But it is soon converted into sugar, which is soluble (i.e. it dissolves in water), and which is therefore in a form that can pass to other parts of the plant. If this part happens to be a storage organ, such as a potato tuber, then the sugar may be converted into starch again as an insoluble storage substance.

Respiration uses some of the oxygen produced in photosynthesis. Photosynthesis uses some of the carbon dioxide produced by respiration. In bright light carbon dioxide will enter the leaf because photosynthesis needs more than the small amount produced by respiration. It also produces more oxygen than respiration consumes so that oxygen passes out. In dim light the overall exchange of gases with the outside balances. Respiration produces enough CO_2 for photosynthesis and the latter produces enough O_2 for respiration. In darkness only respiration proceeds. Oxygen has to enter the leaf while carbon dioxide produced is given off.

Large amounts of an insoluble storage substance can accumulate without interfering with other chemical processes.

Starch is also formed in many seeds and is then available to the young plant inside the seed when it starts to grow. In fleshy storage organs, such as bulbs, sugar may itself be stored. Glucose (grape sugar) is present in large quantities in the bulb of the onion.

The sugar when it arrives at another part of the plant from the leaves may be used to build cell walls. These are made of cellulose, the molecules of which consist of long chains of glucose sugar molecules. Cellulose fibres are used for a number of purposes, particularly in the textile industries (cotton, linen, rayon) and in paper-making (paper consists largely of cellulose). Cellulose is also used as a storage material in some seeds (e.g. lupin).

Sugar may also be built up into fats and proteins. Proteins are built up basically from simple sugars and nitrogen. The plant obtains the nitrogen it needs from ammonium salts or nitrates in solution in the soil. The building up of amino acids from simple sugars and nitrogen and the piecing together of amino acids to form proteins is controlled by enzymes. Small traces of molybdenum are necessary for some of these enzymes to perform these tasks. The living jelly in plant cells (protoplasm) consists to a large extent of proteins and also contains fats. Fats and proteins are also stored in many seeds (e.g. castor oil plant and sunflower contain oils; pea and castor oil plant contain proteins).

Besides being stored, used to build cell walls, or to form other substances such as fats and proteins, sugar is also 'burned' in the cells of the plant to provide energy for work. Growing cells require energy to make cellulose; they require energy to make proteins and fats (whenever a substance releases energy whilst it is burned, energy is needed when the substance is made); energy is needed to move food materials from one part of the plant to another through the food tubes; roots require energy in order to absorb minerals from the soil. The energy for these and the many other everyday chemical processes going on within the cells comes from the burning of sugar. This is called *respiration*.

Seed respiration—a problem

A sample of 20 broad bean seeds weighed 100 gms. After drying for two days in an oven at 120°C. they weighed 85 gms.

After drying for a further day they still weighed 85 gms.

a. What do you conclude from this information?

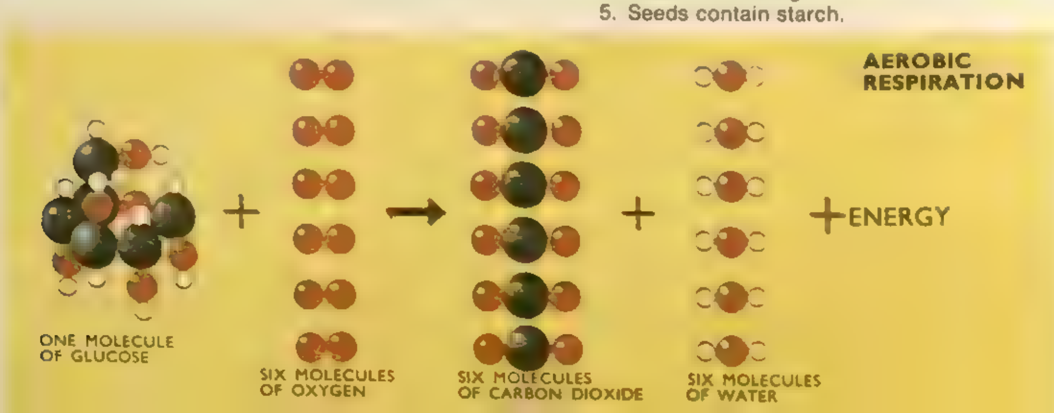
A second sample of 20 seeds was set to germinate after being weighed. They weighed 102 gms. The seeds germinated after one week at room temperature, and three weeks after setting the seedlings were dried at 120°C. for two days.

Their dry weight was 80 gms.

b. What weight could the second sample have been expected to have after drying?

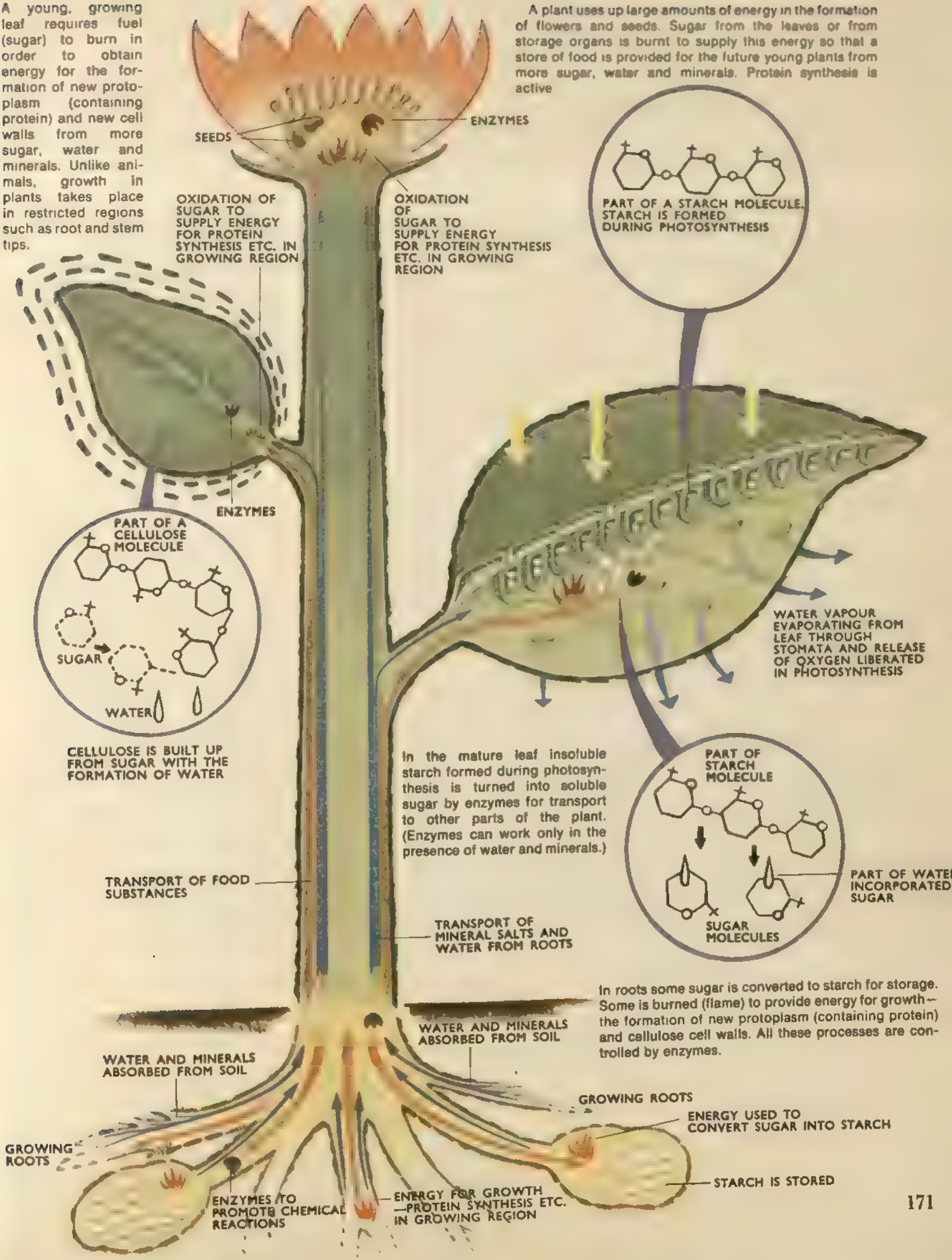
c. How do you account for the difference between expected and observed results?

d. Which of the following facts helps to explain the results?
  1. Germinating seeds take in oxygen.
  2. Germinating seeds give off carbon dioxide.
  3. Germinating seeds release water as a result of respiration.
  4. Germinating seeds are at a higher temperature than their surroundings.
  5. Seeds contain starch.



A young, growing leaf requires fuel (sugar) to burn in order to obtain energy for the formation of new protoplasm (containing protein) and new cell walls from more sugar, water and minerals. Unlike animals, growth in plants takes place in restricted regions such as root and stem tips.

A plant uses up large amounts of energy in the formation of flowers and seeds. Sugar from the leaves or from storage organs is burnt to supply this energy so that a store of food is provided for the future young plants from more sugar, water and minerals. Protein synthesis is active



In the mature leaf insoluble starch formed during photosynthesis is turned into soluble sugar by enzymes for transport to other parts of the plant. (Enzymes can work only in the presence of water and minerals.)

In roots some sugar is converted to starch for storage. Some is burned (flame) to provide energy for growth—the formation of new protoplasm (containing protein) and cellulose cell walls. All these processes are controlled by enzymes.

What factors affect respiration?

Though respiration is taking place at all times the rate at which it proceeds is changing not only with the changing conditions of a day, but also with the seasons and with the stage in a plant's life cycle. There is a large difference between its rate in a dormant seed, between one which has started to sprout (germinate) and a plant at the time of its flowering. Chemical processes will not go on so quickly in the cells of a cactus during the dry season as they will when the cactus is 'refreshed' after a fall of rain. A tree which loses its leaves in the autumn cannot photosynthesise until the new leaves are formed the following year. The rate of respiration in its cells will be lower than it is during the summer not only because that is the time when most growth is taking place but also because the temperature is lower during the autumn and winter. Chemical reactions proceed faster as the temperature increases, up to a certain point (about 35°C to 40°C), and then they decrease because the enzymes are prevented from working and will eventually be destroyed.

The rate of respiration varies with the temperature, the amount of oxygen which is available, the food material which is being burned and its availability, and the supply of water (during a severe drought respiration will be slowed down).

There is no actual burning of sugar in the cells. This is merely a convenient way of describing respiration, since the products of respiration are the same as those produced by the actual burning of sugar, namely carbon dioxide and water, and respiration, like burning, is a process that requires oxygen; it is an oxidation process. More correctly it is a whole series of processes or reactions, in the same way that photosynthesis is not just one simple reaction. Each reaction is controlled by an enzyme and will not take place in the absence of that enzyme. A solution of sugar can be placed in a test tube and given a plentiful supply of oxygen and, providing bacteria and other organisms which ferment sugars are prevented from contaminating the solution, the sugar solution will remain unchanged indefinitely. But when appropriate enzymes are added, then the sugar molecules will be changed.

In the oxidation of glucose, hydrogen and oxygen atoms are removed, forming water molecules. Other oxygen atoms combine with carbon atoms, forming carbon dioxide. This chemical breakdown involves phosphates (the plant obtains its supply of phosphorus from the soil). They are intimately concerned with the transfer of the energy released from chemical breakdowns to the energy consumed in building processes.

In the plant cells (and in animal cells too for that matter) respiration is going on continuously.

Energy is constantly required and is constantly provided to enable reactions to proceed. Chemicals within the cells are constantly being broken down or built up into others with larger molecules. The products of photosynthesis may be combined with the minerals absorbed from the soil by the roots (these minerals are also necessary for some enzymes to do their work), to make chlorophyll and more enzyme molecules. They also make calcium pectate (the substance which cements the cellulose cell walls together), storage products in the seed for the future generation and so on.

The production of seeds, which involves the growth of much new tissue—all the parts of the flower—is a process which requires energy. It is a process which may be concentrated into a very short time. A plant such as a tree regularly flowers each year. During the growing season it is adding branches and producing new leaves, its root system is spreading, more wood is being laid down in its trunk.

Plants are able to respire for a time even in the complete absence of free oxygen (though some animals are able to live in conditions where the amount of oxygen is small, few are able to live in the complete absence of free oxygen). Sugar is the usual food material which is broken down but, besides carbon dioxide, alcohol is formed and not water. After a time the amount of alcohol produced poisons the cells and respiration stops altogether. Respiration in the absence of oxygen is called *anaerobic* respiration; in the presence of oxygen it is called *aerobic* respiration. There is great similarity between anaerobic respiration and fermentation. In both cases sugar is broken down, in the absence of oxygen, to carbon dioxide and alcohol. The same enzymes that enable yeast to ferment sugars have been found in plant cells.

Though carbohydrates (compounds such as

Enzymes

All living cells contain complicated chemicals called enzymes which enable reactions to proceed that would otherwise not occur or would proceed only slowly without help. Enzymes are distributed throughout the living jelly or protoplasm of the cells. They control the speed at which chemical reactions proceed and their quantity and chemical structure remain unchanged at the end of the reactions. They do not alter the substances produced in the reactions. It is thought that enzymes react by forming temporary compounds with the reacting substances, splitting their molecules apart or piecing them together so that smaller or larger molecules are formed. When larger molecules are built up from smaller ones energy is incorporated in them, but when they are broken down energy is released. For example, when foodstuffs are 'burned' or oxidized in respiration, energy is released. This energy is then available for piecing small molecules together to make larger molecules.

The oxygen needed in respiration is carried in the cells by enzymes and these control the changing of chemicals in the cells to other chemicals with the subsequent formation of carbon dioxide and water and with the release of energy.

sugars which contain carbon, hydrogen and oxygen atoms) are the materials that are usually burned to provide energy, fats and proteins may also be respired. For instance, in germinating seeds fats are often respired. Fat is a very economical storage material since it contains proportionately more carbon and hydrogen than carbohydrates or proteins. When it burns, therefore, there is a greater proportion of it to burn than there is of carbohydrate or protein. From the same weights of fat, protein and carbohydrates more energy is released when fat is burnt. More oxygen is needed to burn it than for the other two types of food materials and (of great importance to the seed which needs all the water it can obtain), more water is produced when fat is burned than when carbohydrates or proteins are burned.

Small amounts of protein are probably burned all the time in plant cells, but they are respired in any quantity only when other food materials are in very short supply (i.e., during starvation). For example, they may be respired in leaves which for some reason or other have been unable to photosynthesise for some time so that all the carbohydrates will have been used up and there will be no fats remaining since these are formed from carbohydrates.

From the substances taken in through the roots and those produced in photosynthesis the plant is able to make all the molecules that it needs.

A young mistletoe plant on its host. Both are partly cut away to show the suckers.

Parasites, saprophytes and insect eating plants

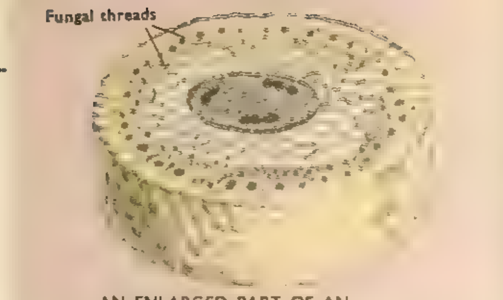
The green plant is able to make its own food in photosynthesis, but some plants (even green plants such as mistletoe) attach themselves to other plants or animals and feed off them. Plants such as these are called *parasites*, and the plants or animals attacked are called hosts.

Other plants called *saprophytes* feed only on dead or decaying matter. Such are the fungi, including many bacteria, mushrooms, toadstools and moulds. Some plants form a very close partnership with other plants and depend on them for their food, though both derive benefit from the relationship *(symbiosis)*. In some instances the relationships are of a special kind between a fungus and a flowering plant. The Bird's Nest Orchid, for example, forms a close relationship with a fungus. Such 'arrangements' are called *mycorrhizas* (mike-o-RISE-az). Yet other plants supplement their food-making processes by catching insects. These *insectivorous plants* have the most remarkable devices for trapping their prey.

A large number of plants are parasitic. Only a few flowering plants feed off others, but a great many fungi are parasites, some of them causing diseases of considerable economic importance. Potato blight, ergot of rye and wheat rust are examples.

Mistletoe is a flowering plant which is a parasite on other plants, such as the apple and hawthorn,

(left) The wheat rust, Puccinia graminis, *attacks the leaves and stems of wheat. During the summer infected wheat becomes coloured orange-red by the spores of the fungus. (right) An ear of rye attacked by ergot. Some of the seeds have been turned black by the masses of hyphae.*



AN ENLARGED PART OF AN UNDERGROUND BRANCH ROOT OF THE BIRD'S NEST ORCHID

MYCORRHIZAS

Though one plant may harm another, there are instances where both partners may benefit from a close relationship. Many plants, particularly those living in soil that contains large amounts of decaying matter, have fungi growing over the surface of, and sometimes inside, their roots. These 'associations' are called mycorrhizas.

The fungi often take the place of root hairs, absorbing water and minerals which the other plant is able to use from the soil. The fungus probably receives a share of the food manufactured by the green leaves of the plant with which it is associated, though flowering plants that have little or no chlorophyll also form mycorrhizas with fungi.

The bird's nest orchid is a saprophyte that associates with a fungus. It obtains its food from the soil with the aid of the fungus. Higher plants such as conifers, the beech and most members of the heather family (ling, heather, etc.) have fungi associated with their roots.

growing high up on their branches. It is unusual, amongst parasites, in that it possesses green leaves and so is able to make some of the food that it requires. It is thus a *partial parasite*, sending out outgrowths (suckers) which penetrate the tissues of the host plant and rob it of the food materials that it has manufactured for itself, also obtaining a supply of water and minerals. The growth of the suckers keeps pace with the growth of the host's tissue so that once they are established they never lose contact with their food supply. Yellow rattle and eyebright are other partial parasites.

The dodder is another parasitic flowering plant. It is a complete parasite, and, like a relative, *Convolvulus* (bindweed), it is a climbing plant. The leaves are tiny scale-like structures that are completely lacking in chlorophyll. The brightly coloured red or yellow stem twines itself round such hosts as nettles, heather or clover. Where it comes into close contact with the host's stem it sends out suckers *(haustoria)* which penetrate the host's tissues and suck up food materials. Once the young seedling has made contact with a host plant its feeble root withers and from then on it is entirely dependent on its host for food. It eventually produces small 'rosettes' of pink flowers in which numerous tiny seeds are produced. This minimises the risk of the next generation being unable to find a new host.

The toothwort is parasitic on the roots of elm and hazel trees. Its underground parts put out suckers which penetrate the roots of these plants and so it obtains nourishment. The broomrapes are also root-

(1) The sulphur-coloured bracket fungus. (2) The fly agaric, a fungus that is poisonous to man. (3) The wood blewit is common in woods and on heaps of dead leaves.

(left) Apple scab is a disease caused by a fungus. (right) A bad attack of potato blight rots the tuber of the potato.

parasites growing on roots of gorse, clover and broom.

There are several noticeable features about these complete parasites. Chlorophyll is nearly always lacking or is present only in minute traces: the leaves, which in green flowering plants are the food-making organs, are much reduced in these parasites and numerous tiny seeds are usually produced. In fact development of the vegetative parts (leaves, etc.) is sacrificed in favour of a high rate of seed production.

Many fungi are parasites, some on other plants, others on animals. Typically the 'body' of a fungus consists of a loose network (mycelium – my-SEAL-ium) of delicate threads (hyphae – high-fee). These are able to penetrate the tissues of the host because they produce enzymes at their tips which dissolve away obstructing cell walls – digesting the cell contents so that they can be absorbed in a simple, broken-down form.

Water moulds are fungi that only live in water. Some attack fishes and amphibians, producing serious diseases. *Saprolegnia* forms loose networks over the gills of fishes, eventually blocking them so that no water can pass in and out carrying the fish's supply of oxygen. The fish may die through lack of oxygen.

Many of the blights and mildews are common pests of other plants. *Phytophthora*, the potato blight fungus, causes a serious disease of the potato plant. After first attacking the leaves and killing them, it then invades the rest of the plant's tissues, eventually rotting the tubers and destroying a whole potato crop. The blight spreads by producing slender stalks on which spores (conidia) are formed. These infect other plants when they are blown about by the wind. In the past potato blight has produced serious potato famines, particularly in countries such as Ireland, where potatoes were the staple food.

The sac fungi include many important parasites. Ergot of rye, black-knot of plums and cherries, apple scab, wart fungi, and the organisms causing leaf curl in peaches, are examples. Ergot infests the seedboxes (ovaries) of such cereals as rye, oats and other grasses. Its activities become noticeable at harvest times, as the seeds are turned black by the masses of hyphae. These drop off the host plant in the autumn and lie dormant during the winter. In the spring they produce spores which are light and may be carried by the wind to infect new hosts. The spores sprout on the host and the hyphae rapidly grow through the ovaries, feeding on the supply of food there. As they grow, more spores of a different kind are produced and a sugary liquid released at the same time. Insects attracted to this trap the spores on their bodies and transport them to fresh hosts as they move from plant to plant.

Many other diseases are caused by sac fungi. The white mildews affect gooseberries, roses, peas, cucumbers, hops and wheat. Other fungi, also called mildews but which are not sac fungi, infect cabbages and grapes. Related to these are the rusts, all of

An insectivorous plant, Venus's fly-trap. Two of the leaves have snapped shut trapping insects inside them.

BOTH DIAGRAMS ARE HIGHLY MAGNIFIED

(left) The blue-green mould Penicillium. Aspergillus *(right) attacks leather and stored products such as grain. Both moulds thrive in damp conditions.*

which are parasites. The best known is probably the rust *Puccinia graminis*, which attacks the stems and leaves of wheat. During the summer infected wheat becomes coloured orange-red by the spores of the fungus. They may be carried by the wind and so infect other plants. Towards the end of the summer clusters of another kind of spore are produced. These are black and survive the winter. In the following spring they sprout (germinate) and produce spores which do not infect wheat, but which infect the leaves of the barberry plant. Eventually new spores are produced on the undersides of the leaves. These spores only attack the wheat plant. The life cycle of the wheat rust thus involves two host plants.

Other rusts attack two host plants while some are confined to one host plant. Control of parasites which have a two-host life history has been possible by eliminating one of the hosts, particularly when this is not economically important. Destruction of the barberry plant has controlled the spread of wheat rust.

Temperature, rainfall and other factors may affect the growth and the spread of parasitic fungi. These factors may also reduce or increase the severity of the diseases that they cause. Potato blight, for example, spreads most readily during spells of warm, damp weather. The effects that they have on their hosts will likewise vary. Leaves may be destroyed and hence the manufacture of food prevented; the blocking of food and water channels may prevent movement of substances from one part of the plant to another. Excessive growth of the host's tissues is common.

Most fungi are saprophytes, that is they live on dead and decaying plant and animal remains. The importance of saprophytes is that by breaking down dead remains they prevent the Earth's surface from becoming littered with great piles of waste. In breaking down the remains they not only obtain food for themselves but they also make substances available to other organisms. Many bacteria are

A pitcher of the pitcher plant in which an insect has been trapped.

Insect-eating plants

Some plants living in marshy or boggy places are able to obtain part of their food by capturing and digesting insects with juices (enzymes) similar to those found in the guts of animals. The insectivorous plants, as they are called, are mainly found in tropical and subtropical regions.

Though insectivorous plants are able to live without their insect food (they all have green leaves which make food by photosynthesis), they produce fewer flowers and seeds if deprived of it. The soil on which they live is poor in minerals, especially nitrates. Insects are a rich source of protein and make a valuable addition to their food.

The intricate devices for trapping insects are specially modified leaves or parts of leaves. In Venus's fly-trap the two lobes of the leaf blade are hinged at the midrib. On their upper surfaces are sensitive hairs. The lobes of the leaf snap together, trapping the insect when these are touched.

Pitcher plants have their leaves modified to form deep pots (or pitchers) that contain water. Downwardly pointing hairs at the top of the pitchers prevent insects that slip into them from getting out. They eventually drown in the water and are digested by enzymes released from glands.

The sundews have their leaves covered with tentacles which produce sticky liquid. Insects are attracted by the glistening tentacles and may be trapped in the gluey liquid. The tentacles then bend over towards the middle of the leaf-blade and the insect is enclosed. Digestive juices are released from glands on the tentacles and the soft parts of the insects are digested.

particularly useful in this respect. Some break down organic compounds in the soil into ammonium compounds. Others convert these to nitrites; yet others convert nitrites to nitrates. Nitrates are the green plant's main source of nitrogen. This circulation of compounds containing nitrogen is termed the *Nitrogen Cycle*. There is a similar circulation of carbon in nature between the organic compounds and carbon dioxide in the atmosphere. Ultimately bacteria break down the organic compounds into carbon dioxide, water, nitrates and other mineral salts. These are the raw materials that green plants require.

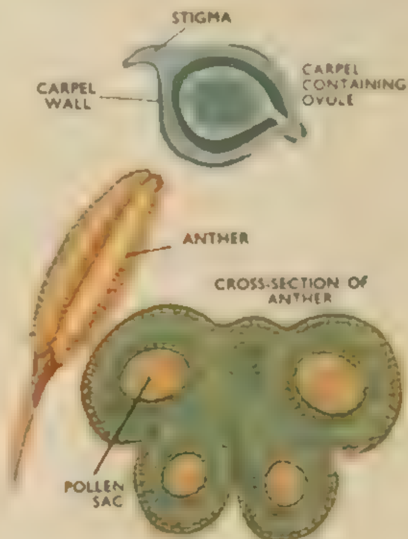
Familiar saprophytes are mushrooms, toadstools, many moulds, mildews and yeasts. Some are of economic importance. The blue-green mould *Penicillium*, for example, is cultured for the production of the drug penicillin.

The function of a Flower

Flower Structure

A FLOWER is that part of a plant concerned with reproducing the species. It contains the essential sexual organs, and frequently a number of accessory organs too.

A simple and fairly typical flower is found in various species of *Ranunculus* (buttercup). The flower is borne on a stalk (the *pedicel*) which is swollen at the top, forming the *receptacle*. The flower parts are arranged on the receptacle usually in concentric circles *(whorls)*, although some flowers (the water-lilies, for example) have their parts spirally arranged. The outer whorl of the buttercup contains five greenish *sepals* which protect the developing flower (the *bud*). Collectively they are called the *calyx*. Inside the sepals there is a whorl of five yellow *petals* each with a small pocket at its base producing nectar and therefore called a *nectary*. The purpose of the petals and nectaries is to attract insects which will carry pollen from one flower to another. The *petals* are collectively known as the *corolla* which, with the calyx, makes up the *perianth*. The sex organs (the essential parts of the flower) are contained within the perianth. In the buttercup they are spirally arranged, but the whorled arrangement is more usual. The *stamens* – the male pollen-producing organs – occur in large numbers. Each consists of a stalk *(filament)* and two pollen-sacs *(anthers)*. The male part of the flower is called the *androecium* as distinct from the female *gynaecium* which is made up of the *carpels* in the centre of the flower. Each carpel contains a female egg-cell *(ovule)* which, when fertilized, will give rise to a *seed*. The carpel is surmounted by a



The structure of a carpel and a stamen.

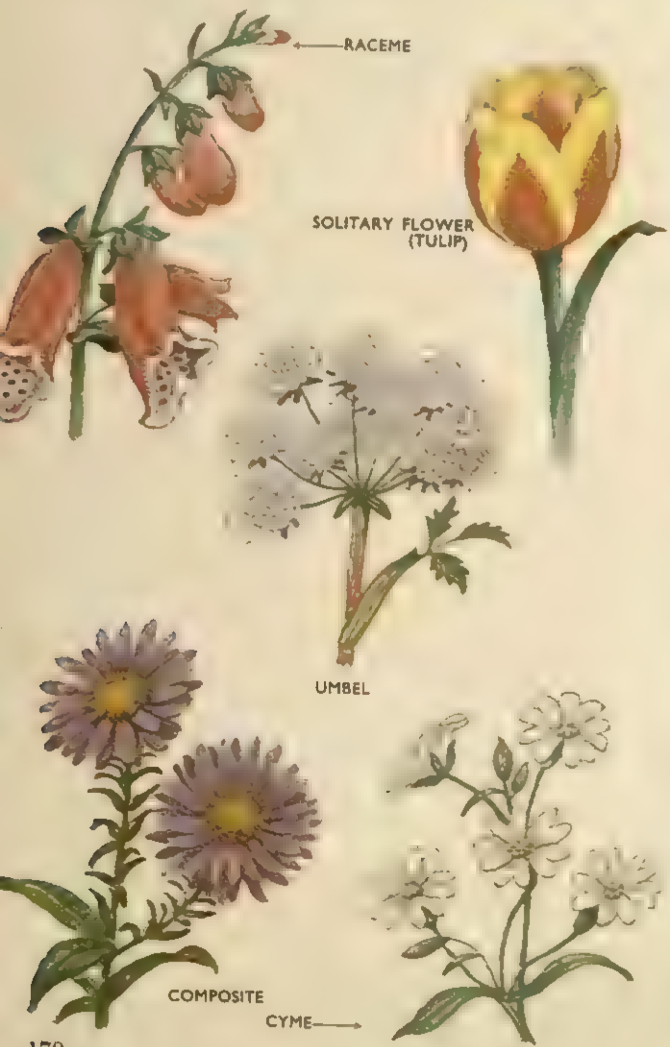
Whorled (left) and spiral (right) arrangements in the buttercup. A section through a buttercup shows the arrangement of the floral organs.

Florets of composites may be tubular (thistles), ligulate (dandelion) or both (daisy).

stigma through which the pollen grain gains access to the ovule.

The foregoing is a brief account of one particular type of flower. Among the various families of flowering plants there is much variation in flower structure. The families are classified according to the essential structure of the flower, although there is a good deal of variation within each family.

The buttercup is a *regular* flower (i.e. the petals are all alike and of the same size). The violet and the sweet-pea are *irregular* flowers in which the petals differ in size and shape. This irregularity is even more marked in some of the orchids.



All types of floral organ are present in the buttercup, but this is not so in all cases. Flowers are often *unisexual*. Hazel catkins, for example, contain only male organs. The female flowers are distinct structures. Male and female flowers may even be borne on different plants. The calyx or corolla may be missing and some flowers may have neither. Petals may be represented by nectaries as in the Christmas Rose *(Helleborus spp)*. The sepals in such cases frequently assume a bright colour and act as petals. Nectaries may arise on any part of the flower, derived from any organ. In tulips both sepals and petals are petaloid (i.e. they both look like petals). The number of parts is not always the same. The whorls usually have multiples of two, four or five members in dicotyledons and three or multiples of three in monocotyledons. Carpels and stamens are often numerous.

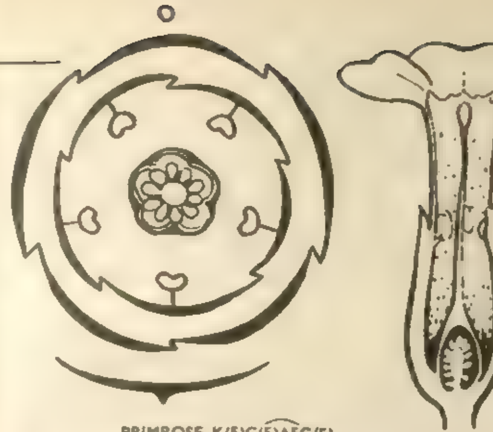
The buttercup is a *hypogynous* flower – the petals and sepals are inserted below the carpels. In a perigynous flower, such as blackberry, they are inserted around the carpels; while in an *epigynous*

The inflorescence

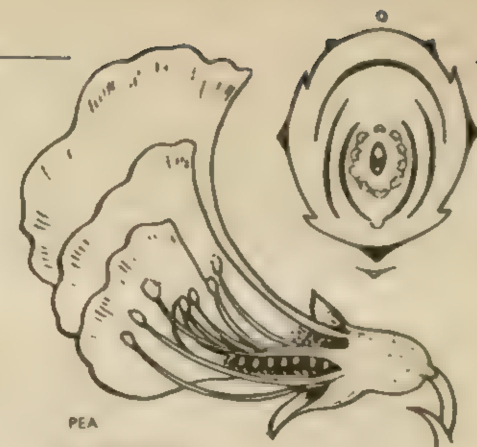
Flowers are sometimes solitary, such as the tulip or the anemone, but more frequently they are borne in groups. The group of flowers on any one stem is called an inflorescence. The type of branching varies a lot and many types have special names. There are, however, two main types, the racemose and cymose. The raceme has a continuously growing apex and flowers develop laterally. They may be stalked, as in the foxglove, or not stalked, as in the pyramidal orchid, forming a spike. Umbels are modified racemes where the flower stalks are given off at one level. Catkins are racemose inflorescences. The cymose inflorescence has each branch terminated by a flower (e.g. stitchwort).

The Compositae (daisies and dandelions) have a very specialised type of flower called a capitulum. It is in fact a whole collection of flowers (florets) arranged on the expanded head of the main stem (peduncle). Each floret has a tiny corolla, which may be a simple tube as in a thistle or it may have a flat 'ray' as in a dandelion or the outer florets of a daisy (the ligulate condition). The sex organs (stamens or carpels or both) are inside the floret.

The calyx is very reduced but later grows as a tuft of hairs (the pappus) which serve to carry the seed away. The Compositae are a very widespread and successful group of plants.



PRIMROSE $K(5)\widehat{C(5)A5}G(\underline{5})$

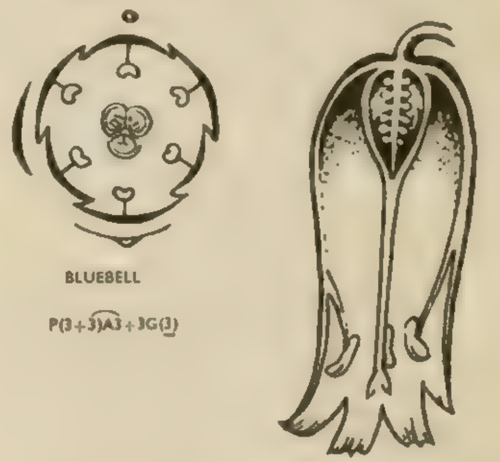


PEA

$K(5)C5A(5+5)G\underline{1}$

Floral formulae and floral diagrams

Botanists (people who study plants) do not need to have a lengthy description of a flower to understand its structure. They use a simple expression—the floral formula. This tells them the number of parts and a good deal about their arrangement. The letters K, C, A, and G stand for calyx, corolla, androecium and gynaecium respectively. P may replace K and C if the sepals and petals are all alike. The formula for a buttercup is $K_5\ C_5\ A_\infty\ G_\infty$, where ∞ means 'numerous'. A line under the carpel figure means that the flower is hypogynous. Above the figure it indicates epigyny. Where parts are joined, brackets surround the figure. The formula does not give a complete description. A floral diagram and a section cut through the flower are required to make the structure quite clear. The floral diagram consists of a plan view of the flower with the organs arranged on circles or spirals showing the degree of overlapping, any fusion or irregularity of parts and the position relative to the main stem of the plant (indicated by a small circle). Leaves on the flower stalks are also shown in the diagram. The longitudinal section shows, among other things, the degree of perigyny. Some examples are given here.



BLUEBELL

$P(3+\widehat{3)A3}+3G(\underline{3})$

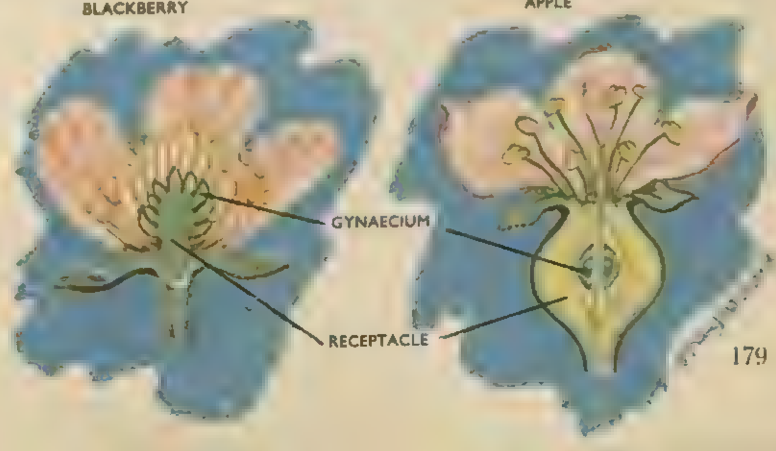
flower the carpels are situated in the receptacle and the perianth is inserted above them. Apple flowers are of this type. The carpels often contain several ovules (e.g. a pea-pod is formed from one carpel with several ovules).

So far we have talked of flowers with a number of separate petals. However, the petals (and sepals) are frequently joined together in the form of a tube. Foxgloves, bluebells and many others are like this. The tube protects the sex organs as a rule, and may also contain a supply of nectar. Very often the carpels are joined.

Irregular flowers are the rule among the orchids. The blackberry and the apple (both members of the Rosaceae) have perigynous and epigynous flowers respectively.

BLACKBERRY

APPLE



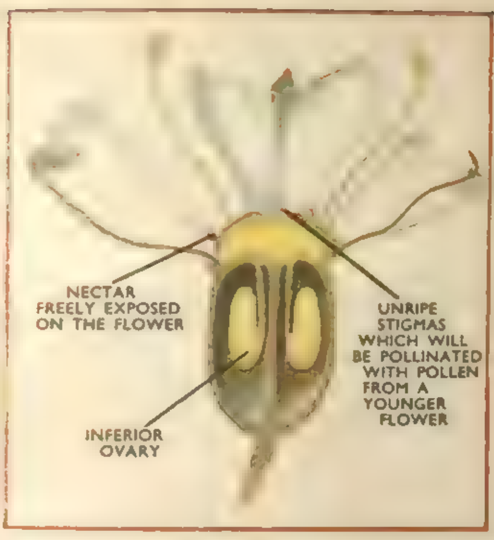
The pollination of flowers

The bees and other insects so commonly seen on flowers during the summer months are not merely feeding on the nectar of the flowers; they are performing a vital service for the plant. As the insects flit from flower to flower they are unwittingly transferring pollen—they are *pollinating* the flowers. The transference of pollen from stamens to stigma is called pollination and is the first stage in the process whereby the male cells gain access to the female egg-cells in order to form seeds. The second part of the process (fertilization) will be described later. All parts of the flower may play a part in pollination but the main organs concerned are the *stamens* and the *stigma*.

Each stamen (male organ) consists of a *filament* and a pair of *anthers* which are the pollen-producing sacs. When the pollen grains are ripe the anther walls split and expose them. The stigma is the receptive surface of the female part of the flower—the *carpel*. The stigma may or may not be on a stalk—the *style*.

When seeds are produced after the transference of pollen from one flower to another *(cross-pollination)*, the resulting plants often grow more vigorously than if the pollen and *ovule* (egg-cell) had both come from a single flower *(self-pollination)*. It is interesting, therefore, that most flowers have some way of avoiding self-pollination and ensuring cross-pollination. Those flowers which are adapted to ensure cross-pollination will produce stronger and more successful offspring which in turn will be adapted for cross-pollination. Most flowers contain both stamens *and* carpels (they are *hermaphrodite*) but a number of plants have flowers of one sex only. A few species (e.g. the willow) even bear the male and female flowers on different plants. In these cases self-pollination is impossible. Where there are organs of both sexes in a flower, self-pollination is often avoided because the anthers and stigmas are separated in space or time. In an upright flower the anthers may be below the stigmas and vice versa in a hanging flower so that pollen will not fall on the stigmas. The most frequent device is that whereby the stamens ripen before the stigma is ready to receive pollen. This is known as *protandry*. The reverse condition *(protogyny)* occurs in some flowers whose stigmas mature before their stamens shed any pollen. A number of plants whose flowers are not structurally adapted to prevent self-pollination are *self-sterile*. The pollen can fall on the stigma but the male sex cell cannot reach within the ovule because there appears to be a chemical barrier to the pollen grain's further development.

Although cross-pollination is preferable, self-pollination is better than no pollination at all and in many cases the stamens and stigmas bend towards each other before the flower dies so that self-pollination may occur if cross-pollination has failed. A number of plants (including the sweet violet)

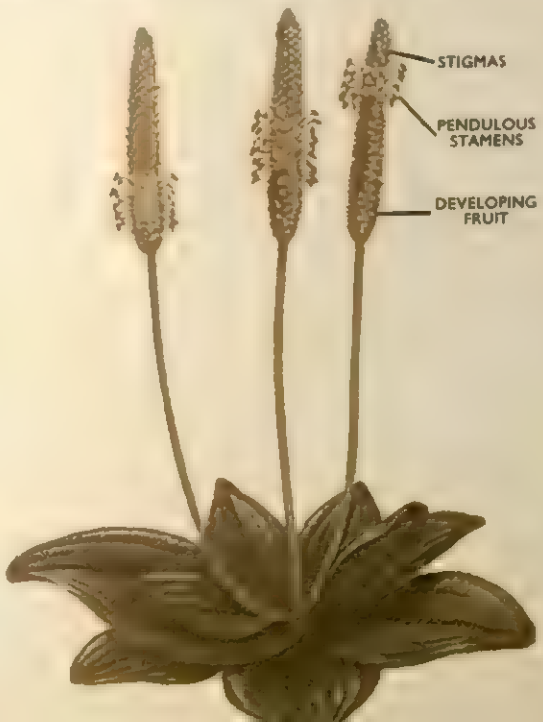


The small 'open' flowers of the hogweed attract many types of insect which effect pollination. (above) A single flower in section.

produce special flowers late in the season which always pollinate themselves—in fact they do not even open: the pollen passes direct from stamen to stigma and ensures that at least some seed will be produced.

Although insects are frequently agents of pollination, there are others, notably the wind. Wind-pollination *(anemophily)* occurs in many trees and all grasses. The flowers are typically borne in catkins or the stamens are provided with long filaments. In both cases even slight air movements release pollen. The pollen is light and produced in large quantities for wind-pollination is wasteful—very little reaches the female stigmas. The latter are usually large and feathery in wind-pollinated plants so that the maximum amount of pollen may be trapped. Wind-pollinated flowers often have no petals and the flowers are normally inconspicuous although well exposed. The hazel-tree produces its male flowers in hanging catkins. The female flowers are tiny structures with branched red stigmas. Separation of the flowers in this way ensures cross-pollination. Grass flowers have very long filamentous stamens which hang well below the stigmas and thus risk of self-pollination is reduced. Plantains produce spikes of protogynous flowers. The lowest flowers open first and expose their stigmas. As the latter wither, the hanging stamens appear, but these rarely pollinate the younger flowers on the same spike since the stamens are always below the stigmas.

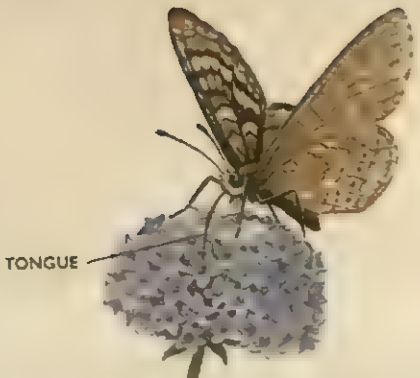
The plantain is wind-pollinated. The lower flowers open first exposing the stigmas. Later the hanging anthers appear.



Insect pollination *(entomophily)* is by far the commonest method of pollen transference. Many flowers are unspecialised and may be pollinated by almost any insect, but the more specialised flowers can be pollinated by only a few species of insect. The elaborate associations between flowers and insects are not coincidental. They are the results of selection which has been acting ever since insects first began to feed at flowers.

The early wind-pollinated flowers must have been attractive to insects in some way—probably on account of the large amount of pollen they produced, for pollen has a high food value. Those flowers which were visited regularly by insects would have been pollinated efficiently and would have produced offspring in larger numbers than the wind-pollinated plants. These offspring too

The outside of a bee's hind leg carries the pollen-basket formed by stiff hairs.

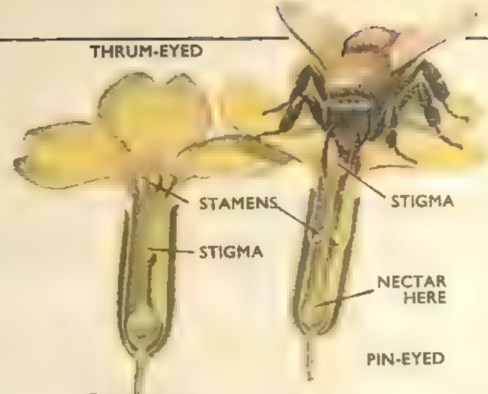


The butterfly's long tongue probes the tubular flowers of the scabious. Tongue and legs all collect pollen.

would have been attractive to insects, and from this stage the many refinements of insect-pollinated flowers must have arisen. The insects, too, have evolved special structures which enable them to gather pollen and nectar (and therefore to pollinate) more efficiently. The 'pollen basket' and the fine feathery hairs of the honey bees illustrate this.

Entomophilous flowers are usually brightly coloured and scented. They normally contain a sweet liquid—*nectar*—as well as pollen, but some flowers (e.g. dog rose) are 'pollen flowers'—they produce no nectar. The pollen of entomophilous flowers is sticky or spiky and adheres to the bodies of insects. Because of the more efficient pollination mechanism less pollen is produced than in the wind-pollinated flowers.

Hazel catkins swaying in the wind scatter pollen onto the red stigmas of the female flowers.



The Primrose

This flower exists in two different forms—'pin-eyed' and 'thrum-eyed'. Each plant has only one type of flower. The difference depends upon the position of the stamens and the length of the style. Primroses are pollinated mainly by long-tongued bees whose tongues pick up pollen at the right level to transport it to the stigma of the opposite type of plant.

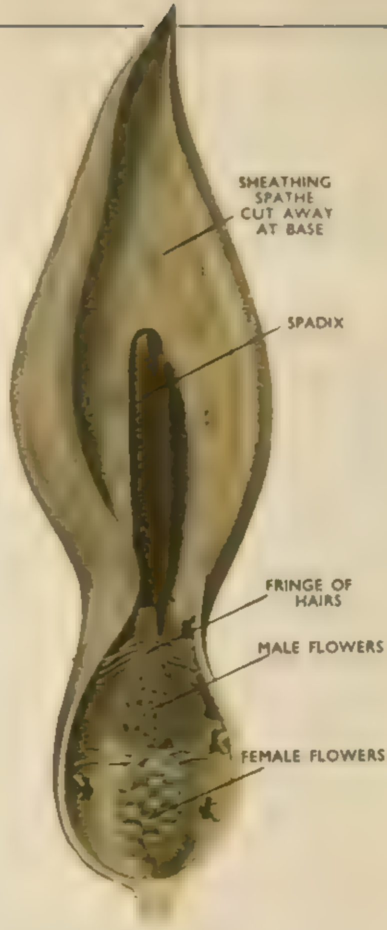
Irregular Flowers

Flowers of this type (e.g. sweet pea) are highly specialised to ensure pollination. Long-tongued bees are attracted to the flowers and settle on the side-petals (wings). The weight of the bee depresses the petals and exposes the sex organs which brush against the insect and pollination is effected as the bee probes for nectar in the base of the flower. Only heavy insects such as bees can pollinate these flowers.

Bees are important pollinating insects. In their search for pollen and nectar they visit large numbers of flowers and pollinate them. The relatively long 'tongue' (proboscis) of bees enables them to find nectar which is *concealed* (e.g. in spurs formed

Orchids

Some of these flowers show the most remarkable adaptations to pollination by certain insects. The likeness of some of the flowers to insects is regarded as a pollination mechanism because it attracts insects to the flower. The flower of the early purple orchid has only one stamen whose anthers are large and contain a sticky mass of pollen (the pollinium) attached to a stalk. When a bee alights on the flower and attempts to get nectar from the spur the pollinia stalks stick to its head and within a short time the pollinia bend forward. They are just in the right position to strike the stigmas of the next plant visited. Flowers of this type are so specialised that only one species of insect may be able to pollinate them.



The cuckoo-pint

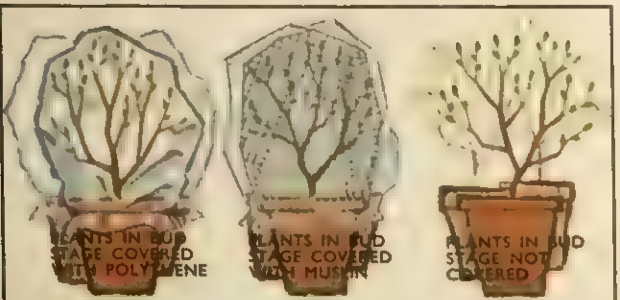
This inflorescence is rather dingy and has an unpleasant odour which is, however, attractive to flies. The individual flowers are borne on a spike, the female flowers below the male ones. Above the flowers is a ring of hairs and the whole spike is sheathed by a bract. Flies, attracted by the odour, crawl down the tube and become trapped below the downward-pointing hairs. The female flowers ripen first and are pollinated by insects with any pollen on them. Then the male flowers ripen and the hairs wither. As the insects escape they gather pollen which they will transfer to the next flower.

by petals). Bees visit flowers which are blue, purple, yellow and sometimes white but rarely visit red flowers. Experiments have shown that the insects are attracted by colour from a distance and then by both colour and scent when they are close to the flowers and that bees can learn to associate certain colours with the presence of a reward (sugar solution). The dark lines on petals *(honey guides)* are believed to guide the insect to the nectar and the stamens and stigma. Butterflies and moths are also

Minor Pollinating Agents

Water carries the pollen of some aquatic plants. The pollen grains have tiny floats which carry them along on the surface until they reach a flower at the surface of the water. Birds are common agents of pollination in the tropics (e.g. Humming birds). The flowers are usually red and produce large amounts of nectar. Bats may be pollinators of some flowers, again especially in the tropics. Other animals may effect pollination during their wanderings but they are not regular pollinators.

important agents. Butterflies visit all types of flower, chiefly red and white ones. Their long tongues can reach nectar in tubular flowers. Night-flying moths hover in front of flowers and reach the nectar with their long tongues. The flowers are usually white or yellow (so that they are easily seen at dusk) and strongly scented (e.g. honeysuckle). Their stamens and stigmas protrude from the flower, touching the hovering moth. Other insects which frequently visit flowers include flies and beetles. These are not specialised for reaching concealed nectar and are normally found on 'open' flowers such as those of the family *Umbelliferae* (e.g. hogweed). Heads of flowers are frequently covered with insects which feed upon the exposed nectar. The flowers are markedly protandrous and the insects transfer pollen from the younger flowers in the centre of the head to the outer, older flowers whose stigmas are ripe. Flowers of the family *Compositae* are also visited by various types of insect. Most entomophilous flowers that are not self-pollinated employ one of the methods described above to avoid self-pollination.



Pollination Problems

1. A sample containing different species of plants was divided into three groups.
   Group 1 flowers were covered while still in the bud stage with polythene bags.
   Group 2 flowers were covered with muslin while still in the bud stage.
   Group 3 were left uncovered.
   It was found that species A B & C produced fruit in all three groups. Species D and E did not form fruits in group 1, but did in groups 2 & 3, but types F G & H only formed fruits in group 3.
   Explain the results.
2. Try this experiment practically on buttercups. Which types ABC – DE – FGH do they resemble?

From flower to fruit

Seed formation in flowering plants depends upon pollination and fertilization. Not only must the pollen come into contact with the female stigma – it must germinate there and one of its cells must join (fuse) with the egg-cell *(ovule)* in the carpel.

Pollen grains at first are single-celled bodies with two coverings. The outer one is often patterned, thus making it possible to identify a plant species by its pollen grains. By the time the pollen reaches the stigma, its nucleus has usually divided into vegetative and generative nuclei. The latter then divides again to give two *male cells (gametes)*. A fine tube emerges from the grain and grows down through the stigma and style (when present), carrying the nuclei with it. This *pollen tube* appears to be chemically attracted to an ovule which it enters via the micropyle.

The carpel is the female organ of the flower. There may be one or more in each flower and each carpel may contain one or more ovules. It is the ovule that gives rise to the seed. The shape of the ovule varies but it is normally attached to the carpel wall in the manner shown. There are two layers of covering cells *(integuments)* surrounding a layer of nutritional tissue (the *nucellus*). Within this is the *embryo-sac* which contains the egg-cell nucleus and a number of other nuclei (see illustration). When the pollen-tube enters the micropyle, its tip and the vegetative nucleus disintegrate and the two gametes enter the embryo-sac. One fuses with the egg-cell nucleus and the other with the two endosperm nuclei. This is the act of *fertilization* and is followed by changes in the ovule associated with seed production. The exact details vary from one species to another but the general case is described below.

The fused egg-cell begins to divide rapidly and gives rise to the structures of the new plant. These are the *plumule* (young shoot), *radicle* (young root) and *cotyledons* (seed leaves). There are two cotyledons in seeds of dicotyledonous plants while monocotyledons have only one seed leaf. These young structures as a whole are called the *embryo*. While the embryo is developing the fused endosperm nuclei also divide many times and produce cells of the endosperm. This is the tissue which nourishes the embryo when the seed germinates. It contains starch, protein and other food reserves. Many seeds, however, have no endosperm when mature. It is absorbed, as it is produced, by the cotyledons

The pea pod (legume) is a simple fruit derived from a single carpel containing several ovules.

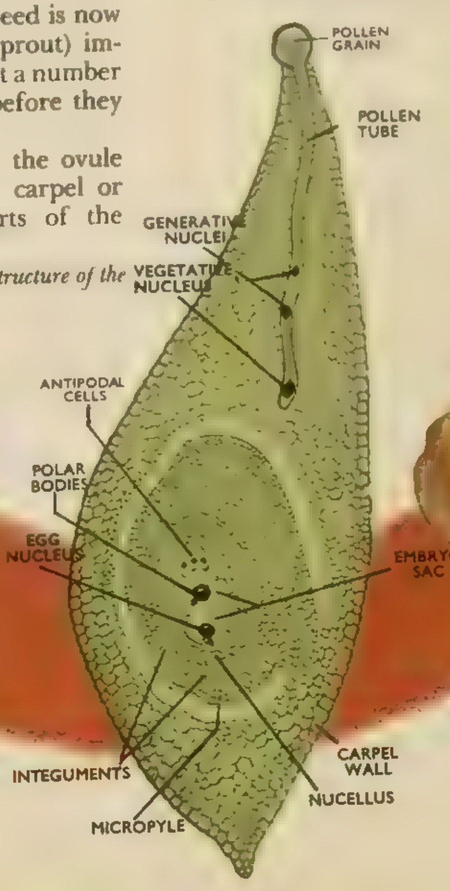
which eventually take up most of the seed and nourish the germinating plant themselves. The runner bean is a good example of the *non-endospermic* seed, having large fleshy cotyledons. The development of the endosperm and the embryo is at the expense of the nucellus and is also supported by food from the parent plant which passes through the ovule stalk. The outer coverings of the seed are derived from the integuments of the ovule which become tough and sometimes leathery.

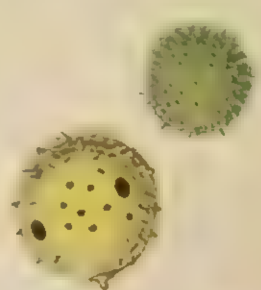
Development of the embryo does not normally go on indefinitely. Cell division slows down and stops after a while and the seed as a whole loses water. The outer covering *(testa)* becomes very hard and breaks away from the carpel wall. The seed is now ripe. Many seeds will germinate (i.e. sprout) immediately if given the right conditions but a number require a definite period of *dormancy* before they can develop into new plants.

Whereas the seed is produced from the ovule alone, the fruit is produced from the carpel or carpels and often includes other parts of the flower too. Its purpose is to protect and distribute the seeds. A fruit may contain one or many seeds. Fruit production is normally triggered off by fertilization but in some cases pollination may provide the necessary stimulus. This is of a chemical nature and it is now possible to produce seedless fruit artificially by applying the correct hormone to the flower.

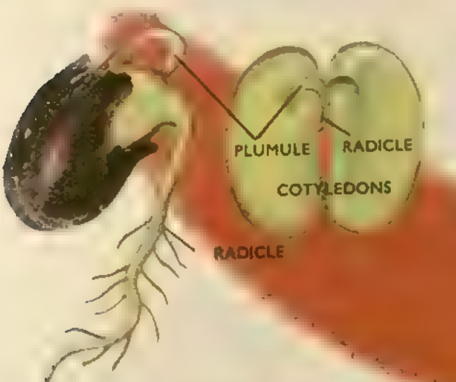
Fruits derived from the carpel alone are called *true fruits* while those which contain other organs as well are called *false fruits*. Another classification is into dry and fleshy fruits but this is not a clearcut division. Dry fruits are further subdivided according to the way in which they open to liberate the seeds.

Simple fruits are those which are derived from a single flower with one carpel or a number of fused

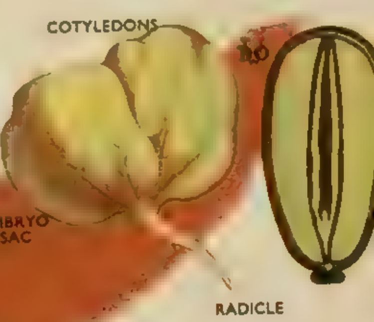




The carpel of the buttercup in section to show the structure of the ovule and the germinating pollen grain.

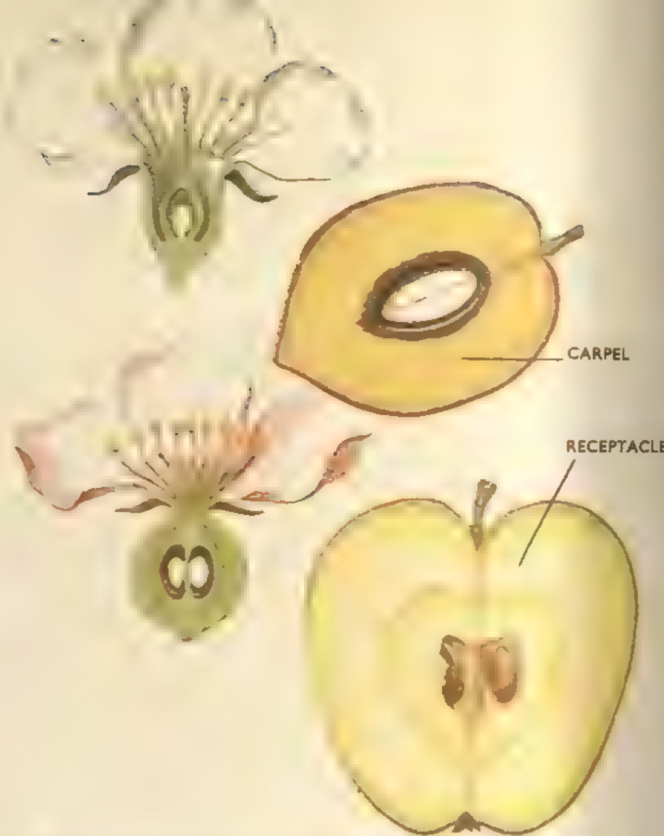


The runner bean seed (split open above and germinating at left) has large fleshy cotyledons and small radicle and plumule.



The castor-oil seed has a large store of oily endosperm in which is embedded the embryo dissected out at left.

The pineapple is a composite fruit formed by the fusion of many flowers.



(top) The plum is a true fruit formed from the single carpel of the flower. The stone is the inner layer of the carpel wall. (below) The apple is a false fruit. The receptacle and outer carpel wall become fleshy while the inner carpel wall becomes horny and forms the 'core' of the fruit.

ones. The layers of the carpel wall give rise to the layers of the fruit *(pericarp)* which may be dry or fleshy. Examples include the hazel nut, the pea pod (one carpel with several seeds), *berries* such as the orange and tomato (both several seeds and several carpels), and *drupes* such as the plum. A drupe differs from a berry in that the inner layer of the carpel produces a hard 'stone'. The plum stone is *not* a seed—it is part of the fruit and contains a seed. Drupes normally have only one seed but berries contain more as a rule. Dry fruits containing several seeds usually split open and scatter the seeds, but single-seeded ones (e.g. hazel nut) do not normally split; the pericarp rots on the ground and the seed germinates. Flowers in which the carpels are separate give rise to *compound fruits*. The buttercup produces a collection of small nuts *(achenes)* while the blackberry fruit is a collection of drupes.

False fruits include the apple and the strawberry among many others. These two both include the receptacle in the fruit. The apple carpels are surrounded by the receptacle which swells to form the fleshy part of the fruit. The carpel wall becomes horny (the core of the apple) and contains the seeds or pips. Fruits of this type are called *pomes*. Other pomes are the pear, hawthorn and rowan fruits. Strawberries are swollen receptacles which carry a number of small true fruits (the so-called pips') formed from the separate carpels.

Composite fruits are those which are formed from whole inflorescences, not single flowers. Examples are figs, pineapples, mulberries. Bracts, sepals and flower-stalks all take part in forming these fruits.

The dispersal of fruits and seeds

The adaptations that make a flowering plant so well fitted for life in a particular place are probably not so obvious as those of an animal. Animals move about, they can be observed doing things, using their special structures as they go about their everyday tasks. Nevertheless there are many clear outward signs of a plant's adaptations and its activities: such as when the air is filled with the downy-white 'chutes' of thistles and dandelions; the sight of hundreds of sycamore 'keys' winging their way to earth as they drift in the wind or that of holly and

(top) Blackberries are compound fruits made up of several small drupes each derived from a single carpel. (centre) The orange is a berry derived from several carpels whose outer walls produce the peel. Each carpel is fleshy and may contain one or more seeds (pips). (bottom) Strawberries are false fruits produced from swollen receptacles. The pips are the true fruits of the plant—each from a separate carpel.

Practical Problems

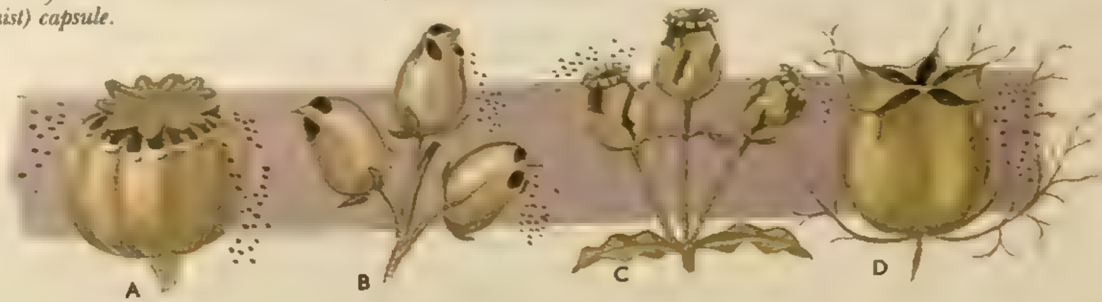
1. *Fertilization failure.* Collect 50 ripe lupin pods. Count the number of seeds per pod and the number of ovules per pod. Does the number of ovules always equal the number of seeds? How do you account for any difference you observe? What is the variation in the number of seeds per pod? Find a clear diagrammatic way of summarising all the information you have gathered.
2. *Germination failure.* Plant 100 seeds from different plants of the same species on wet filter paper in shallow dishes. What percentage fail to germinate? How could you extend this investigation to find out if there was any connection between the number of seeds produced by a plant and the percentage failure of seeds to germinate, or to find the connection between the number of plants in an area and germination failure?
3. *Dispersal investigation.* Sterilize enough rich soil to fill three seed trays, by raising its temperature to 100°C. for 1 hour. Now place the trays open to the air in different situations at any time after say May 1st. As late as possible in the summer term, or early in the autumn term compare the numbers of different kinds of plants which 'colonise' the boxes. How can you find out the least possible distance the fruits have travelled? How could you modify the experiment to sort out the wind-dispersed fruits from the animal-dispersed fruits?

hawthorn trees covered in conspicuous red fruits. All these show that the plant has fulfilled its task of producing seeds—seeds containing the embryos, some of which will grow into new plants and which in turn will produce their own seeds. They thus ensure that their race will survive.

The seeds of wild plants run many risks and most of them do not have a chance to germinate, which is why most plants produce such large numbers. If those that germinated merely fell beneath the parent plant their chance of survival would be small. Animals could easily find such accumulations and devour them, seedlings produced would be overcrowded, competing with one another for water, light, air, etc., and disease would spread rapidly among them. Also the plant species would not spread and colonize more distant areas with its own kind. It would thus live in a limited area only and be subject to complete extinction if some local catastrophe occurred. The fact that seeds are scattered or *dispersed*—sometimes to great distances, sometimes to a few inches only—by a variety of devices considerably increases their chances of success.

The seeds alone may be dispersed or they may be carried within the fruit. Many are dispersed by *wind* or by air currents, being very small and light, like the seeds of orchids and foxgloves or having 'wings' like the seeds of the pine or the fruits of the ash, maple, elm and the sycamore. Other plants such as the dandelion, milkweed, *Clematis* (old man's beard), willowherb, cotton, willow and poplar have seeds or fruits with hairy outgrowths that act as parachutes. Such devices enable fruits and seeds to remain airborne for great distances, often many miles. 'Wings' are not so effective, though the num-

Dispersal by wind—censer mechanisms. (a) Poppy capsule. (b) Capsules of snapdragon. (c) Campion capsules. (d) Nigella *(Love-in-a-mist) capsule.*



Explosive or propulsive mechanisms. (a) Fruits of stock shown before and after splitting. (b) Pods (legumes) of Laburnum. *(c) Capsule of violet before and after splitting. (d) Balsam capsule before and after splitting.*

ber of plants that possess winged seeds or fruits is a testimony to their efficiency.

Plants such as the poppy, the bellflowers (e.g. harebell), and campions have so-called *'censer-mechanisms'*. The seeds are contained in a capsule (the fruit) which opens by way of pores or teeth, or which may split lengthwise. In the harebell, which has hanging fruits, the seeds are ejected through the pores of the capsule as it sways, even in the lightest breeze. The capsules of the poppy and the pink are borne at the end of stiff but flexible stalks. The seeds are catapulted out of the capsules when the stalks recoil to an upright position, having been bent over by the wind.

Relatively few plants have fruits or seeds adapted for dispersal by *water*. This is mainly restricted to those that live near or in water. Such are the coconut palm, alder and water lily. A coconut (strictly a *drupe*) has a thick fibrous outer covering – the *coir* which is used to make coconut matting and which has been removed from coconuts that are sold in the shops. This outer layer is light and buoyant and enables the coconut to be carried many miles by water. The ancestral home of the coconut palm is thought to be Malaysia and it is probable that the plant became established on the east coast of Africa and in many tropical islands because the fruits were distributed by ocean currents.

The seeds of water lily and alder have a spongy covering, the *aril*, containing numerous tiny pockets of air. This enables them to float great distances.

Animals play a vital part in distributing seeds. Many plants have brightly coloured fruits that are fleshy and so made attractive to animals. The seeds are usually protected by a hard covering. The hard part of the fruit containing the seed may never be swallowed. The fleshy part may merely be nibbled or pecked at – and the hard interior dropped.

In mistletoe the flesh of the fruit is sticky and adheres to the beak of the birds that feed on it. A bird often scrapes the remains of its meal off on a tree branch and in so doing the mistletoe seed is conveniently sited for the developing seedling to attach itself to the plant on which it lives. On the other hand, it may be that the whole fruit is swallowed, and though the fleshy part is digested, the seed may pass unharmed through the digestive system and be deposited with the faeces at some other place. The hard covering may be softened so that the seed germinates much more readily. But many seeds are digested having been broken up by the powerful teeth of mammals, for example, or by the beaks and the muscular gizzards of seed-eating birds.

The fleshy part of a fruit may develop from various parts. In drupes (e.g. cherry, holly, plum, apricot) and berries (e.g. grape, mistletoe, orange) it is formed from the ovary wall (these are all *true* fruits). In pomes (e.g. apple), the strawberry, and

the rose hip, the flesh is formed from the very swollen receptacle (these are *false* fruits).

Occasionally the seed itself may be fleshy. In the yew and the spindle tree the seed coat is enclosed in a brightly-coloured structure, the *aril*. This develops after fertilization.

Castor oil and gorse seeds have small, fleshy, oil-containing bodies developed at one end. Apparently the oil is attractive to ants which play a major part in the dispersal of the seeds.

Many fruits and seeds adhere to the coats of animals by means of hooks. Such structures are particularly developed by small herbs. In goosegrass, carrot and enchanter's nightshade the fruits are hooked. The upper part of the receptacle in agrimony is hooked. In burr marigold the calyx is reduced to small spiny bristles, and in avens the styles persist and are hooked.

When they become wet the seeds of plantain and chickweed become sticky and adhere to the fur of mammals and the feathers of birds. Many small seeds and fruits are dispersed on the feet of animals (e.g. water-birds), becoming trapped in mud on their feet.

Nuts are often dispersed by rodents such as squirrels. Often they are buried in the ground and if uneaten they may be in an ideal position to germinate.

In many instances the seeds are propelled some distance by an explosive mechanism. Dispersal may be due to the unequal drying of the ovary wall (*pericarp*) or to its saturation with water. Unequal drying sets up tensions which lead to the forced rupture of the fruit. Thus the seeds are projected some little way from the parent plant. This is the means of dispersal in legumes such as the pea, gorse and broom, in stocks, evening primrose, shepherd's purse and *Geranium*.

The fruits of balsam and squirting cucumber absorb water and become swollen. Eventually the pressure ruptures the fruit wall and the seeds are thrown out.

Germination

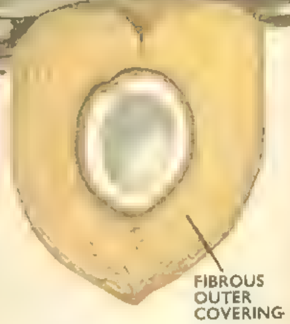
The action of frost, heat from the sun, and wind dry the soil causing it to crack and break up. Rain washes the seeds into these. Many of the soil's in-

Animals are important agents of seed and fruit dispersal. (above) A mistle-thrush wipes the remains of a sticky mistletoe fruit off its beak on to a branch. (below) A goldfinch shakes off some of the fruits from plantain while consuming others; a squirrel with a hazel nut; an ant carries off a gorse seed.

habitants (e.g. earthworms, ants) pull seeds into their burrows. Some fruits are rough and hairy and cling to the soil. When the fruit of oat becomes wet it lengthens and pushes its way into the damp soil. Many seeds also become buried by falling leaves and other debris.

Thus seeds become buried in the soil in a variety of ways. They are more protected than they would be if they remained above ground. In the spring when the soil warms up, providing they have adequate supplies of water and oxygen, they will sprout or *germinate*.

At the time of germination the seed takes in large quantities of water, gradually losing its wrinkled appearance. Sometimes the seed coat is stretched so much that it bursts. The energy needed for growth is obtained from the food store in the seed. In the broad bean the seed leaves or cotyledons are food storage organs. In others (e.g. castor oil) the food store is outside the embryo in a special tissue – the *endosperm*.

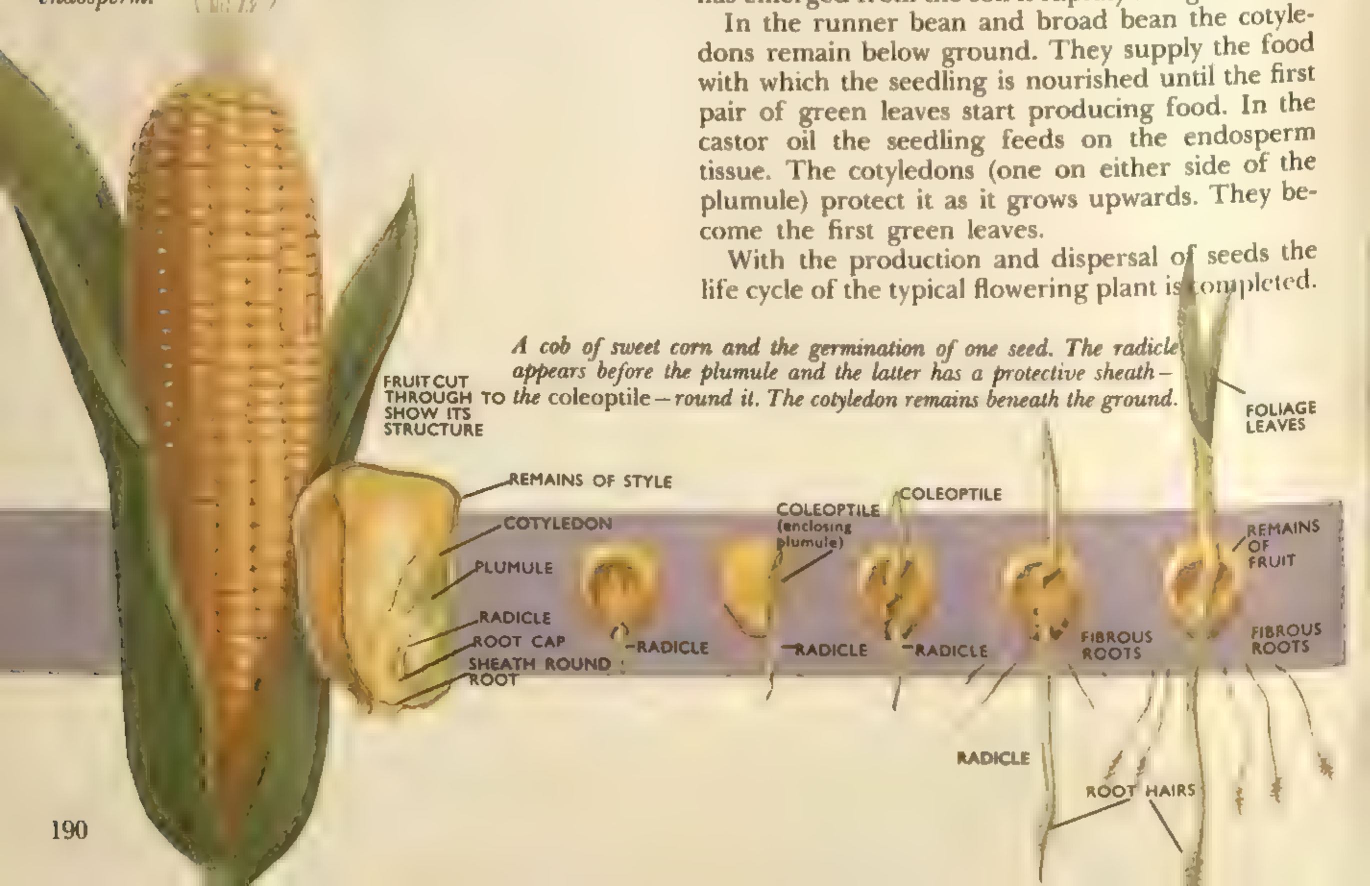


Dispersal by water – water lilies in a pond. Insets: (left) a seed showing its spongy covering or aril, *(right) section through a coconut showing the fibrous outer covering.*

Usually the young root or *radicle* is first to emerge through the seed coat. It grows downwards (in response to gravity) into the soil. The young shoot (*plumule*) appears shortly afterwards growing upwards. Its tip remains bent over until the surface of the soil is reached or broken, thus the brunt of the plumule's passage through the soil is taken by an older part and the fragile tip is protected. Once it has emerged from the soil it rapidly straightens out.

In the runner bean and broad bean the cotyledons remain below ground. They supply the food with which the seedling is nourished until the first pair of green leaves start producing food. In the castor oil the seedling feeds on the endosperm tissue. The cotyledons (one on either side of the plumule) protect it as it grows upwards. They become the first green leaves.

With the production and dispersal of seeds the life cycle of the typical flowering plant is completed.



A cob of sweet corn and the germination of one seed. The radicle appears before the plumule and the latter has a protective sheath – the coleoptile *– round it. The cotyledon remains beneath the ground.*

When the seed germinates the life cycle of another generation is beginning.

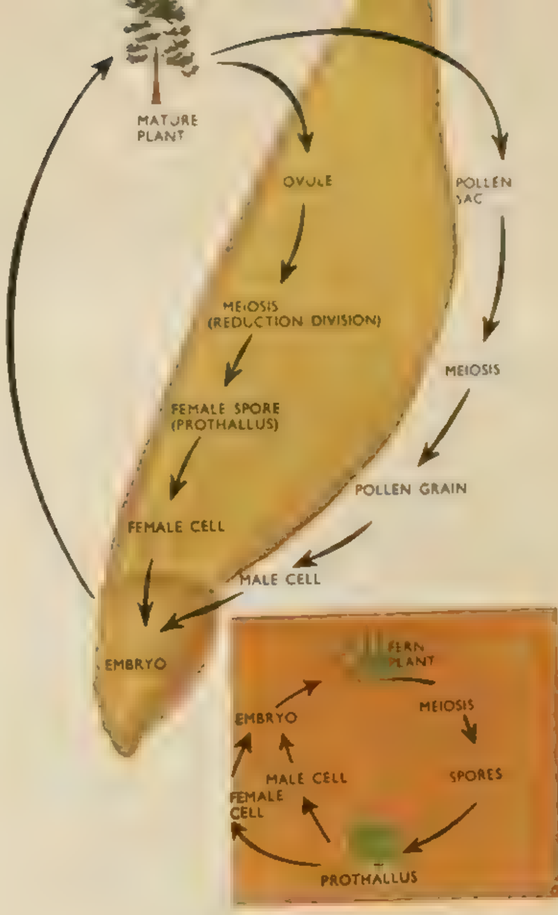
Spores and seeds

Mosses and ferns distribute themselves over the surface of the Earth by means of tiny structures called *spores*. When these spores grow, however, they develop into plants quite unlike the parent. This is most obvious in ferns—the tiny green prothallus is very unlike the large leafy fern plant which carried the spores. Sexual structures develop on the prothallus and produce male and female cells. The joining together of two sex-cells produces an embryo which grows into a new leafy fern plant. This plant can produce spore capsules and spores. The occurrence of two stages in the life history is called the 'alternation of generations'.

Every body-cell of a plant or animal has a certain number of *chromosomes*. The number is fixed for each species. When reproduction takes place by the joining of two cells there has to be a process whereby the chromosome number is halved at some stage. The process is called *meiosis*. In most animals it takes place during the formation of the sex-cells so that the reduced chromosome number (*haploid* condition) is found only in these cells. The body cells have the full (*diploid*) number. Meiosis in ferns takes place during the formation of the spores, thus the spores and the prothalli are haploid. The sex-cells that they produce are also haploid but when they join to form embryos the diploid number is regained. Most ferns produce only one type of prothallus, but in a few species the male and female cells develop on separate prothalli and there are in fact two types of spore—one producing a male prothallus and the other a female one.

Flowering plants and conifers (i.e. seed-bearing plants) always produce two types of spore, though not necessarily on the same plant. As in ferns, meiosis takes place during spore formation. Only the male spore (*pollen grain*) is released. The female spore remains and develops in its capsule (*ovule*) and produces one or more female cells. In the pine, there is virtually a prothallus *within* the enlarged spore. Pollen grains reach the female structure with the help of wind or insects and then divide to produce a male cell. Male and female cells join and form an embryo. Conifers and flowering plants have thus avoided the stage of the free-living prothallus. The female cell is produced and fertilized without the spore ever leaving its capsule.

As the embryo grows, it absorbs food from the *nucellus* (the main tissue of the ovule). Material from the nucellus also passes into the prothallus or (in flowering plants only) into a special tissue called

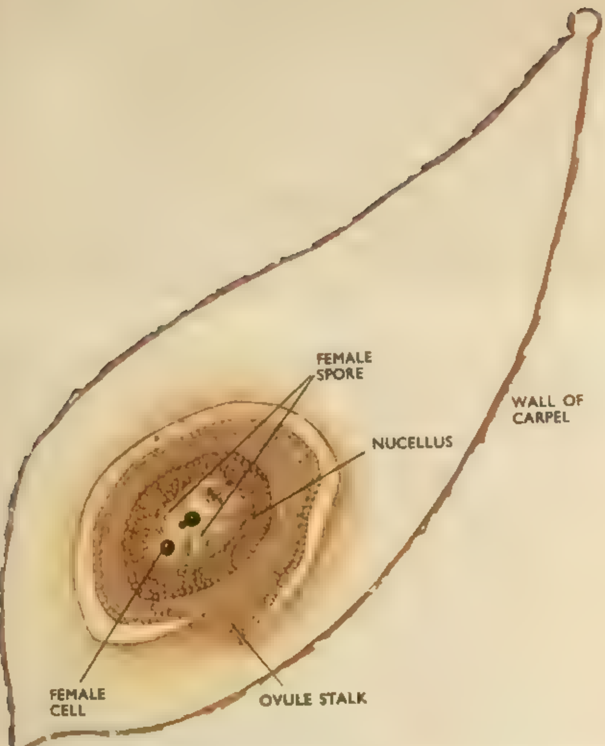


(top) The life cycle of the pine. The formation and fertilization of the female cell takes place while still attached to the parent plant. The seed is not shed until the embryo is well formed. Compare with the fern life cycle (inset).

endosperm. The material is stored as a food reserve. The whole arrangement, still inside the ovule, is called the *seed*. A mature seed consists of the outer covering (developed from the ovule covering), the remains of the nucellus, food reserve and embryo.

In many flowering plants the endosperm has only a short existence—the food is rapidly absorbed into the seed-leaves (cotyledons) which become large and fleshy (e.g. runner bean).

The embryo consists of a *radicle* (root), *plumule* (stem) and *cotyledons* (seed leaves). Of the latter there are several in a pine seed. Flowering plants have either one or two cotyledons and are grouped therefore into *Monocotyledoneae* and *Dicotyledoneae*. When the embryo reaches a certain stage of development it slows down, water is removed from the seed and the seed-coat hardens. The seed is now ripe and can be released. The seeds of flowering plants are always enclosed within the carpel which forms the fruit, but those of conifers are naked.

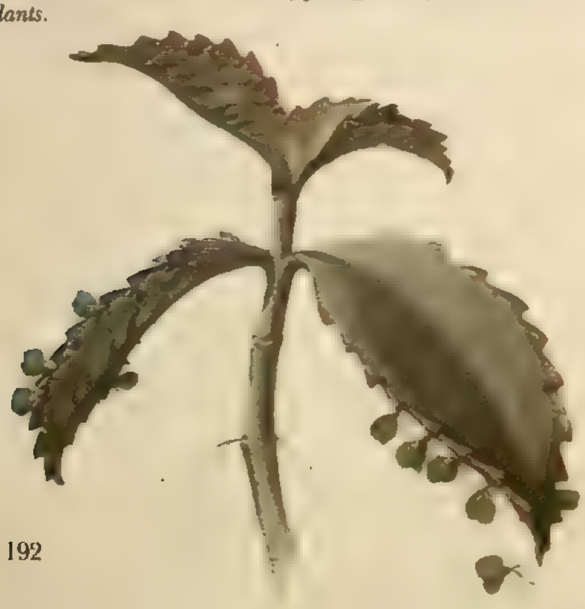


The ovule (female spore-chamber) of a flowering plant showing the female spore within.

They are carried on the surface of the scales that make up the cones.

Seeds are resistant to cold and to drought but when suitable conditions occur they will absorb water and begin to grow. The early stages of germination and growth are supported by the food reserve within the seed. The seed is, therefore, a very efficient method of reproducing the species—

Bryophyllum, *the familiar house-plant, produces many small plantlets on its leaves. Later they fall off and grow into mature plants.*



Carnations are propagated (increased) in the garden by pegging down slit shoots which then take root. The process is called layering.

a great advance over the condition where a tiny prothallus, exposed to the elements, is a vital stage in the process.

Vegetative Reproduction

The term 'reproduction', applied to flowering plants, normally brings to mind the processes of pollination and seed formation, followed by distribution of seeds. How, then, does a thick sward develop on a lawn whose grass is regularly mown and not allowed to produce seed? The answer is that new plants are produced by *vegetative reproduction*. Modified shoots grow from the parent plants and produce complete new plants, at first attached to the parents, but later becoming independent. Eventually a dense mat of grass is produced.

Vegetative reproduction occurs throughout the plant kingdom. The vegetative organs (i.e. stems, roots, leaves) give rise to new plants. *Asexual reproduction* by means of spores is carried on by a number of lower plants. Special organs develop and give rise to *spores*—tiny single-celled bodies which develop into new plants when conditions are right. Spores are frequently protected by hard shells and can withstand cold and drought. Reproduction by normal vegetative means, however, is no safeguard against bad weather.

The simplest form of vegetative reproduction is found in many algae and fungi. Such plants are made up of thread-like branches—*hyphae*. If any of these hyphae are broken, both parts continue to live and grow as separate plants. Mushroom 'spawn' is of this nature. The hyphae of the cultivated varieties can be broken up and each piece will grow and produce fruiting bodies—the mushrooms. The green 'scum' on a pond is made up largely of simple algae (e.g. *Spirogyra*) which consists of numerous filaments. These grow in length by addition of new cells and frequently break. Each part produces a new thread and so the scum builds up.

Liverworts (allied to the mosses) often reproduce themselves by forming *gemmae* (pronounced: jemmy). These are small bodies (buds) which form

Strawberry plant with runners produced in summer.

in pits on the plant surface. They are normally distributed by water splashes or trickles, since the plants grow only in wet areas. The buds grow immediately into new plants.

Higher plants—especially the flowering ones—display a number of modifications for vegetative reproduction. Many are made use of by gardeners as quick ways to raise new plants. It is quicker than growing from seed and also ensures that the new plants will have the same character (e.g. flower colour) as the parents. This cannot be guaranteed always with seed because of the way in which the characters are inherited. The least specialised method is that found in plants such as the wild thyme whose stems creep over the ground and form roots from some of the nodes. A large area is quickly covered and numerous new plants are formed if the older central plant should die away. *Layering*, artificial pegging down of stems to encourage root formation, is a common method of increasing some garden plants. Strawberry *runners* are slightly more specialised creeping stems. They develop at a certain time of the year (mainly in summer) and grow rapidly by the lengthening of the internodes. Roots and leaves develop at the ends (and at some of the other nodes) forming new plants. The length of the runners reduces the competition between the parent and the offspring. Branches of blackberry plants frequently take root when they bend over to the ground. The prickles curve upwards.

Suckers are shoots which arise underground and grow to the surface to form aerial parts. They may develop on underground stems as in mint or on roots as in roses. The sucker remains attached to the parent for some time and does not contain much food reserve. This is in contrast to the *rhizomes* of irises and solomon's seal. These are underground stems whose food reserves enable the plant to per-

(left) Marram grass is extensively planted on sand-dunes where the creeping rhizomes help to bind the loose sand together. (centre) The rose sucker originates from the root *and later develops roots of its own. As most roses are grown on briar roots, the sucker will be a briar too. (right) Bulbils formed in the leaf-axils of coral root* (Dentaria) *fall to the ground and produce new plants.*

sist from year to year. Many grasses, too, have creeping rhizomes which are responsible for the development of large clumps of grass. Marram grass is extensively planted on sand-dunes where the rhizomes help to bind the loose sand and prevent it from being blown away.

Corms, *bulbs* and *tubers* (root and stem) are all food storage organs which produce new plants when separated. The gardener relies on these as a means of increasing his supply of flowers and vegetables.

Leaves too may be concerned with vegetative reproduction. Those of various begonias and African violets—both common pot-plants—will take root and form complete plants if detached from the parent. A number of plants produce buds on the leaves. The buds may or may not develop into small plants before dropping off to begin their separate existence. Buds which drop off the plant before opening are called *bulbils*. They are well shown in the wild leek, where they often replace flowers, and in the coral root. Pieces of stem often take root if removed from the plant. The practice of taking cuttings and vine 'eyes' depends upon this.

Although vegetative reproduction helps a species to colonize a given small area quickly, it does not help to extend the range of the species. Seeds are produced normally by most of these plants so that new and distant habitats can also be colonized.

Sensitivity

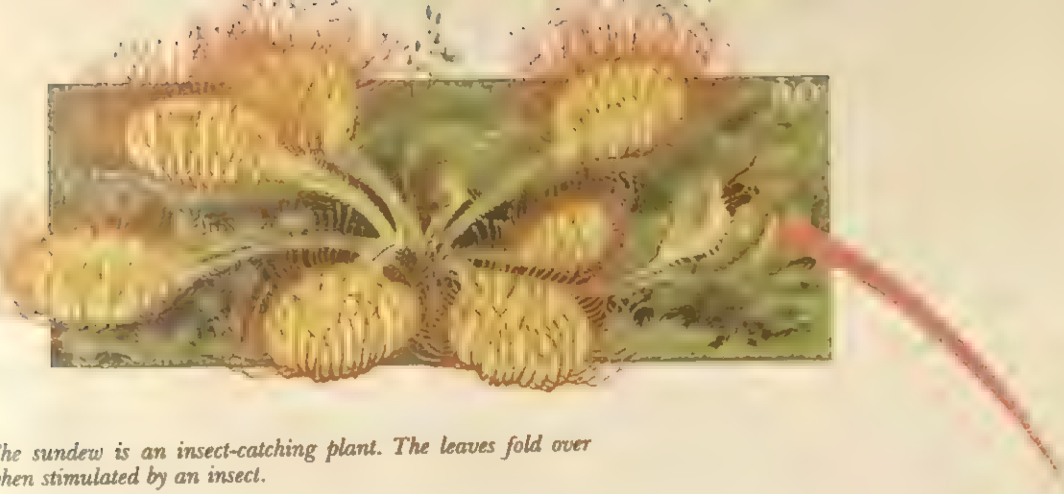
ANYONE who grows plants on a window-sill knows that they move. The shoots bend over towards the light and the pots must be turned round. Next day, however, the shoots are again bent towards the window. The stems are reacting to a stimulus—the stimulus of light in this example. Such bending responses are called *tropisms*. Because the stem bends towards the light it is said to be *positively phototropic*.

Oat seedlings are commonly used in growth experiments. This experiment shows, by covering or removing the tip, that the latter controls movement. Only the normal seedling bends over towards the light.

When seeds are sown, no matter what way up they fall, the shoot will grow upwards and the young root downwards. This can easily be seen if bean seeds are germinated in a jar. The root and stem are reacting to the stimulus of gravity. Main roots are *positively geotropic* and grow down in the direction of the force of gravity. Main shoots are *negatively geotropic* and grow upwards. These responses are very important, for the main functions of the root are to anchor the plant and to absorb water and dissolved salts, while the stem serves to display the leaves and flowers to the Sun.

Light, gravity and water are the three main stimuli to which plants respond. Water has little effect upon stems but its unequal distribution in the soil can have a strong effect upon roots. In fact, the

Young seedlings in full light are normal. Those grown in the dark are elongated and spindly. When illuminated from one side, the shoots bend over towards the light.



The sundew is an insect-catching plant. The leaves fold over when stimulated by an insect.

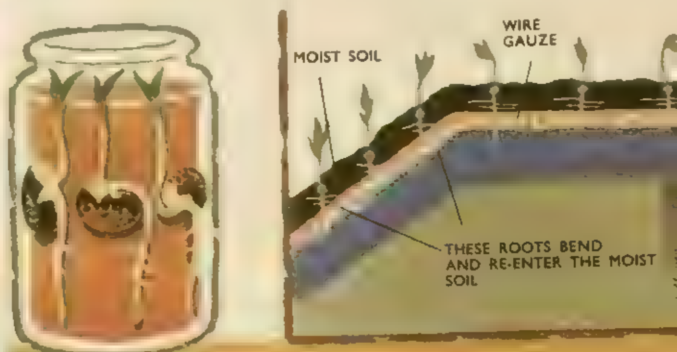
response to water can outweigh the response to gravity. This can be demonstrated very well by the following experiment.

A piece of wire gauze is fitted into a light-proof box and arranged as shown in the illustration. Soil is added and kept moist and suitable seeds (e.g. peas) are sown in it. The young roots grow down under the influence of gravity and go through the gauze. If the whole arrangement is removed from the box, or if a window is cut in it, the behaviour of the roots can be seen. Those on the sloping part react to the water stimulus on one side and grow back into the soil—thus ignoring the effect of gravity. Roots in the central part however do not experience the unequal distribution of water, and continue to grow downwards. The box must be light-proof or it could be argued that light was causing the roots to re-enter the soil.

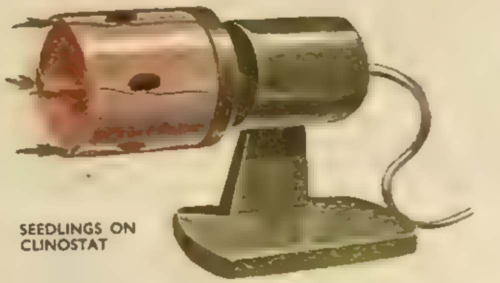
When a stem or root grows in a curve, the outside of the curve must grow more quickly than the inside. This response develops just behind the tip (in the zone of elongation). It is the actual tip, however, that is sensitive to the stimulus and controls the response. If the tip is removed, there is no response. However, if the tip is then replaced, a response is noted. The tip of the root or stem produces a substance that diffuses back and controls elongation. This growth substance has been isolated and is called *auxin*.

It is now generally accepted that growth curves develop as a result of unequal distribution of auxin. Experiment has shown that more growth substance

The tip of an oat-seedling is removed and placed on two gelatin blocks. When illuminated from one side, more growth substance collects in the dark side. If the blocks of gelatin are put on the cut shoots they produce bending even in the dark. This proves that bending is due to some chemical agency. The amount of bending depends on the amount of auxin in the blocks.



No matter what way up a seed is sown, the root goes down and the stem up. However, in the right-hand picture, the effect of moisture overcomes the effect of gravity and the roots curve back into the soil.

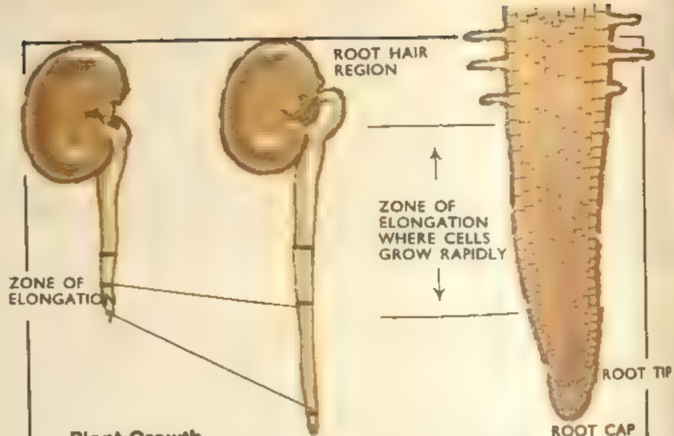


Experiments to show the effect of gravity
In order to show that the plants are definitely responding to gravity we must have some means of avoiding its effect in a control experiment. This is done by using a machine called a clinostat. It is a turntable, driven by clockwork or electricity, on which plants or small pots can be fixed. If it is rotated about a horizontal axis, the effect of gravity will be the same on all sides and the result is the same as if there were no gravitational force. Young seedlings are the best for demonstrating these effects for they grow quickly and respond rapidly to stimuli. If some are fixed to the clinostat in a jar as shown and others are left in a fixed position, the effects will soon be seen. The stationary seedlings bend upwards at the shoot and downwards at the root. Those on the clinostat remain horizontal. This experiment should be carried out in total darkness or in full light because light can interfere with the effect of gravity, if it is not equal on all sides.

is produced in the shaded side of a stem tip than in the illuminated side and that this leads to greater growth on the shaded side. The stem then curves towards the light.

In a horizontal stem tip, more growth substance accumulates on the lower side. Growth is more rapid on this side and the stem curves upwards. In a stem, more auxin promotes growth. Roots, however, are exactly opposite. The accumulation of growth substance in the lower side checks growth and the upper side lengthens more rapidly: the roots bend downwards.

How the unequal distribution of growth substance comes about is still disputed. It has been suggested that the effect of light destroys the auxin. This would explain why fully illuminated plants are shorter than those grown in the dark. Another suggestion is that tiny electric currents are responsible for transporting the auxin. Gravity may be



Plant Growth
The tips of roots and stems are the actual sites of cell division. Here, masses of tiny new cells are formed. A short way behind the tip these cells begin to enlarge. This is the zone of elongation where most of the growth takes place. That growth occurs mainly in this region can be shown by marking a root with dye. The divisions become separated most rapidly just behind the tip. Growth substances produced at the tip control the rate of elongation of the cells.

involved in the accumulation of auxin in the lower parts of shoots but none of these explanations fits all the evidence and more work is required to solve the problem.

Many flowers can be made to close up by exposing them to lower temperatures or by reducing the amount of light. The daily rhythm of some flowers is, however, internal and the rhythmic opening and closing takes place even in total darkness. Similar rhythms are known in some leaves, e.g. *Mimosa*. Auxin does not seem to be concerned in these movements. The *Mimosa* leaves collapse because water is removed from some of the cells.

A practical problem
To investigate the action of indolyl acetic acid, a substance extracted from growing shoot tips, on the growth of cress seedling shoots. Indolyl acetic acid can be purchased as auxin paste made up in lanolin or it may be made up as a ·001% solution in lanolin.

a. Sow 50 cress seedlings on wet cotton wool in a petrie dish in neat rows.
b. Keep the seedlings in the dark at room temperature for 14 days.
c. With the tip of a seeker smear one side of the stem, near the tip, with lanolin plus auxin, treating one third of the sample in this way. Treat a further third with lanolin alone, and leave a third untreated.
d. Return them to the dark and observe 24 to 48 hours later.
e. What is the similarity between the effect observed and the growth of seedlings grown in light from one side? Invent a theory to explain how the response to light from one side works, bearing in mind that indolyl acetic acid has been found in shoot tips.

Index

ACKNOWLEDGMENTS

The assistance of the following in providing reference material for this book is gratefully acknowledged:
F.A.O.; Glaxo Laboratories Limited; Mr. K. C. Richardson; Medical Research Council; Laboratory of Molecular Biology; Professor J. Z. Young; Fisons Fertilizers Limited; Eric J. Hewitt.Esq., University of Bristol; The Crookes Laboratories Limited.